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# STUDY THE KAISER EFFECT OF ACOUSTIC EMISSION SIGNAL DURING TENSILE TESTING OF GFRP COMPOSITE

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## ABSTRACT

In this work, Kaiser Effect of acoustic emission signal during tensile testing of GFRP (reinforcement: E-glass fiber, matrix: Poly-ester resin) composite studied. The Kaiser effect fails most noticeably in situations where time- dependent mechanisms control the deformation. The rheological flow or relaxation of the matrix in highly stressed composites in a prime example. A flow of the matrix at loads below the previous maximum can transfer stress to the fibers, causing them to break and emit. Other cases where the Kaiser effect will fail are corrosion processes and hydrogen embrittlement, which are also time dependent. The AE waveform of GFRP specimen found more burst type signal this mainly due to individual fibers breakage.

**KEYWORDS:** Tensile testing, Acoustic Emission Signal (AE signal), Kaiser Effect, Glass Fiber Reinforced Polymer (GFRP)

## INTRODUCTION

Acoustic Emission (AE) is the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from a localized source or source within a material or the transient elastic wave so generated (ASTM). Josef Kaiser is credited as the founder of modern acoustic emission technology and it was his pioneering work in Germany in the 1950’s that triggered a connected, continuous flow of subsequent development [1-2]. He made two major discoveries. The first was the near universality of the acoustic emission phenomenon. He observed emission in all the materials he studied. The second was the effect that bears his name. In the translation of his own words: “Tests on various materials (metals, woods or mineral materials) have shown that low-level emissions begin even at the lowest stress levels (less than 1 MPa or 100 psi). They are detectable all the way through to the failure load, but only if the material has experienced no previous loading. This phenomenon lends a special significance to acoustic emission investigations because by the measurement of emission during loading a clear conclusion can be drawn about the magnitude of the maximum loading experienced prior to the test by the material under investigation. In this, the magnitude and duration of the earlier loading and the time between the earlier loading and the test loading are of no importance [3-5]. This effect has attracted the attention of acoustic emission workers ever since. In fact, all the years of acoustic research have yielded no other generalization of comparable power. As time went by, both practical applications and controversial exceptions to the rules were identified. The main objective of this research is to study the Kaiser effect during tensile testing of GFRP (reinforcement: E-glass fiber, matrix: Poly-ester resin) composite. The research also study the AE parameters like the counts to peak, AE Rms, Amplitude, AE hits and AE waveform correlates with tensile properties and various failure modes of GFRP composite.

## EXPERIMENTAL DETAILS

## MATERIALS AND EXPERIMENTAL PROCEDURE

The GFRP composite laminate of 4 mm thickness made of E-glass fiber and Poly-ester resin as the matrix manufactured by ECAMS RESINS PVT LTD is used in this study. The mechanical properties of GFRP fiber/resin details E-glass fiber and Poly-ester resin is given in Tables 1 to 3. The un-notched tensile specimens of GFRP, Al, Cu, and HCS were prepared as per the ASTM E8M-04 standard guidelines for monitoring the AE signal. Tensile testing was carried out using 100 kN Electro mechanical controlled universal testing machine (Make: FIE-blue star, India; Model: UNITEK-94100).

**Table 1: Mechanical Properties of E-Glass Fiber and Polyester Resin**

| Fiber/resin | Tensile Modulus ($E$) (GPa) | Tensile Strength ($\sigma$) (MPa) | Density ($\rho$) (g/cm$^3$) | Shear Modulus | Ultimate Elongation (%) |
|---|---|---|---|---|---|
| E-Glass | 69 | 2400 | 2.6 | 27 | - |
| Polyester | 3000 | 50 | 1.10 | - | 2% |

**Table 2: Details of E-Glass Fiber**

| Fiber, E-glass(M123 300-130 1B) | |
|---|---|
| **Manufacturer** | **OCV$^{TM}$ Reinforcements** |
| M123 | Chopped Strand Mat(CSM) |
| 300 | Roll weight(g/m$^2$) |
| 130 | Roll width(cm) |
| 1B | Number of trimmed edges(zero,one or two) |

**Table 3: Details of Poly-Ester Resin**

| Resin, Poly-ester | |
|---|---|
| **Manufacturer** | **ECAMS RESINS PVT LTD.** |
| Product | Ecamalon 8811(Isothalic based resin) |
| Hardner | MEKP(Methyl Ethyl Ketone Peroxide) |

## ACOUSTIC EMISSION SIGNAL MONITORING

The AE data Acquisition setup, AE sensor with preamplifier as shown in Figure.1 and 2, piezoelectric AE transducer was fixed on the tensile specimen using couplant made of Physical acoustic corporation Ltd (PAC) frequency range of 0-1000 kHz, before each test, the calibration of the acquisition parameter was achieved by performing a pencil lead break procedure [9].

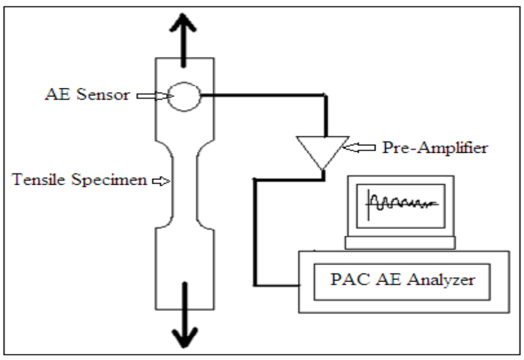



**Figure 1: AE Data Acquisition Setup**

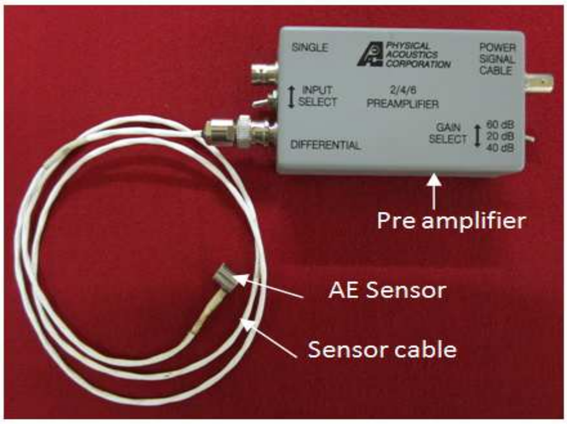



**Figure 2: PAC AE Sensor with Preamplifier**

Electric signal produced by the transducer was of very low amplitude and high-frequency content and was initially amplified with a low noise pre-amplifier. Most pre-amplifier had a gain of 40-60 dB. In this study 40 dB pre-amplified gain is used [6-7]. The pre-amplified signal was passed through a band pass filter with a threshold set greater than background noise; the conditioned signal was stored in the computer and analyzed using AE Win software. The acoustic emission monitored for the entire testing of all the specimens and tensile properties correlated with AE parameter.

## RESULTS AND DISCUSSIONS

## TENSILE PROPERTIES

The transverse tensile properties such as yield strength, tensile strength, and percentage of elongation of GFRP material were evaluated. Three specimens were tested, and the best one selected. The tensile testing results are presented in Table 4. The load vs. displacement curve for without aging as shown in Figure.3. The another one set of specimens used for study Kaiser Effect in this specimen load applied just above yield point and below braking load. Then load removed specimens permitted strain aging, aging period 6 months used in this study. After 6 months the same specimens again tested and load vs. displacement curves as shown in Figures. 4 & 5. The same tensile specimen's acoustic emission signal also captured before and after aging for further analyzes. The yield strength and tensile strength of GFRP material before and after 235, 268 MPa 70, 89 MPa respectively.

**Table 4: Transverse Tensile Properties of GFRP Composite**

| Property | Without Aging | After Aging |
|---|---|---|
| Yield Strength(MPa) | 235 | 70 |
| Ultimate Tensile Strength(MPa) | 268 | 89 |
| %Elongation In 50 mm Gauge Length | 13.92 | 10 |

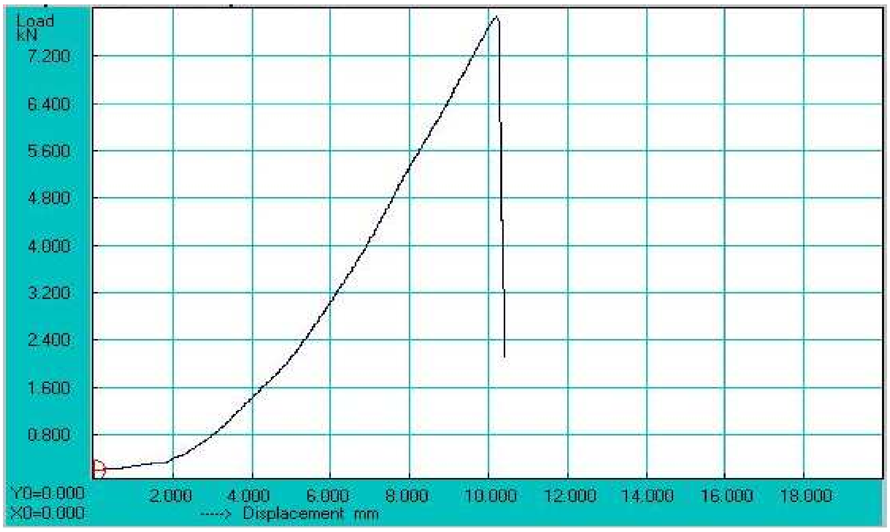



**Figure 3: Load Vs Displacement Curve (Without Aging)**

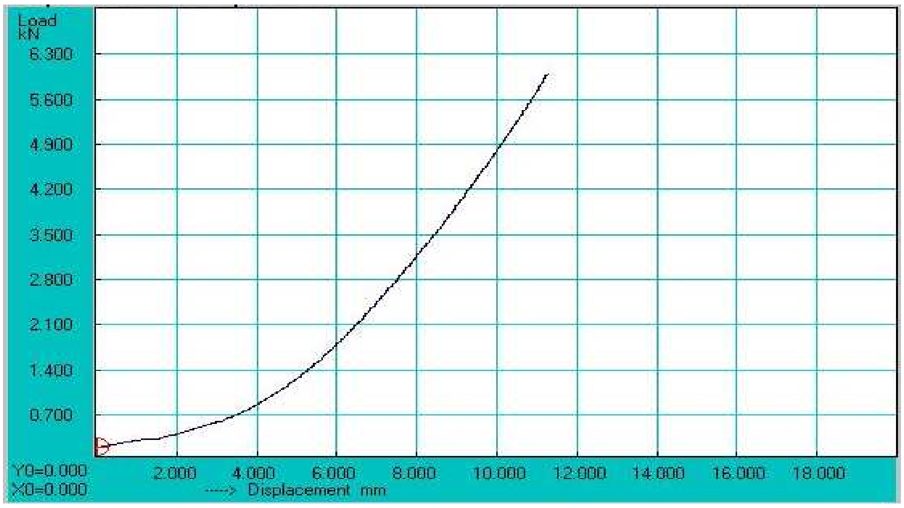



**Figure 4: Load Vs Displacement Curve (Before Aging)**


**Figure 5: Load Vs Displacement Curve (After Aging)**

## ACOUSTIC EMISSION SIGNAL MONITORING

### Irreversibility and the Kaiser Effect

An important feature affecting acoustic emission applications is the generally irreversible response from most metals. In practice, it is often found that once a given load has been applied and the acoustic emission from accommodating that stress has ceased, additional acoustic emission will not occur until that stress level is exceeded, even load completely removed and then reapplied. This often useful (and sometimes troublesome) behavior has been named the Kaiser effect in honor of the researcher who first reported it [8].

The degree to which the Kaiser effect is present varies between metals and may even disappear completely after several hours (or days) for the alloy that exhibits appreciable room temperature annealing (recovery) characteristics. Some alloys and materials may not exhibit any measurable Kaiser effect at all [9].

### Kaiser Effect on GFRP Composite

The AE parameters during GFRP specimen before and after strain aging are shown in Figure.6 & 7. From Figures, it observes that GFRP specimen emission is often observed at loads lower than the previous maximum (Figure 4 & 5), especially when the material is in poor condition or close to failure. This breakdown or failure of the Kaiser effect was successfully used to predict failure loads in GFRP composite components.

The discovery of cases where the Kaiser effect breaks down was at first quite confusing and controversial but eventually, some further insights emerged. The Kaiser effect fails most noticeably in situations where time-dependent mechanisms control the deformation [10]. The rheological flow or relaxation of the matrix in highly stressed composites in a prime example. A flow of the matrix at loads below the previous maximum can transfer stress to the fibers, causing them to break and emit. Other cases where the Kaiser effect will fail are corrosion processes and hydrogen embrittlement, which are also time dependent.

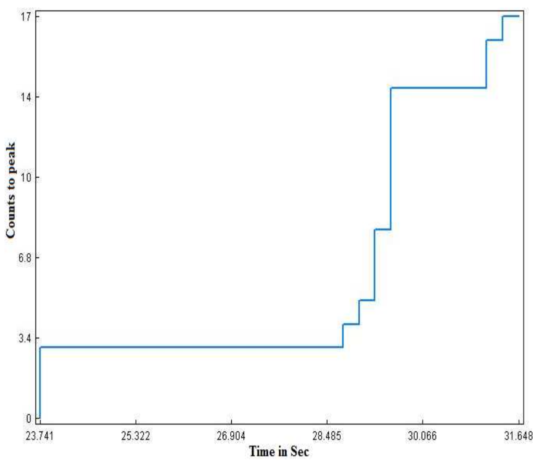



Figure 6 (a): Counts to Peak

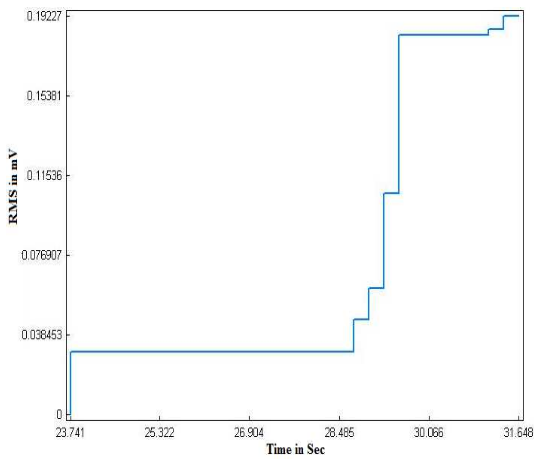
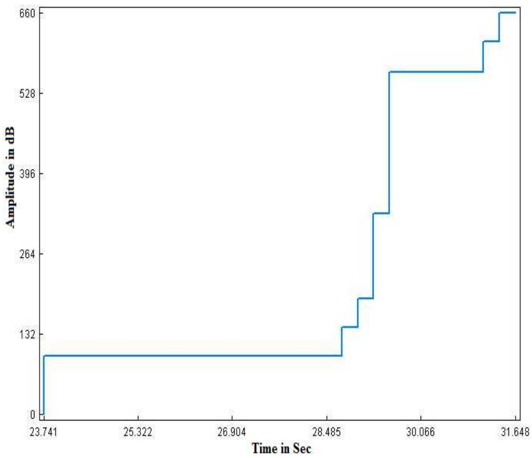



Figure 6 (b): Rms



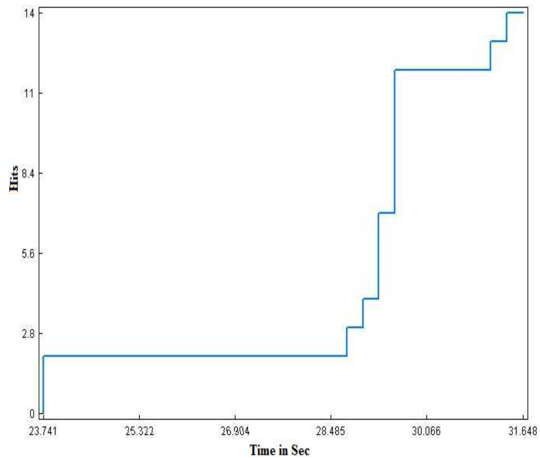
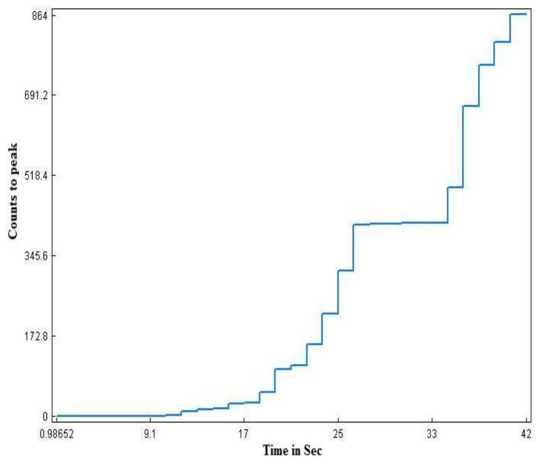




**Figure 6 (c): Amplitude** **Figure 6 (d): Hits**

**Figure 6: AE Parameters Vs Time for GFRP Laminate (Before Aging)**

Three stages until failure is visible. The first stage corresponds to the initial stage of loading, up to 23.7 seconds, the variation of counts to peak, AE Rms, amplitude and hits vs. time is almost flat, which indicates matrix micro-cracking [11]. The second stage further loading results damage accumulation in which the matrix micro- and macro-cracking progresses: this is indicated by a sudden and abrupt increase in counts to peak, AE Rms, amplitude, and hits. The final sharp increase in the counts to peak, AE Rms, amplitude and hits is deemed representing fiber-matrix deboning and fiber failure.



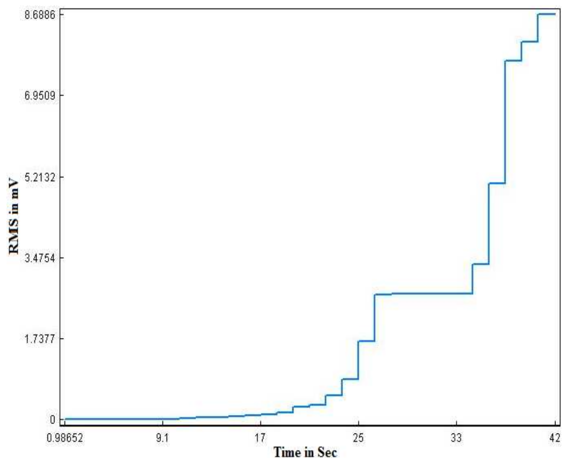
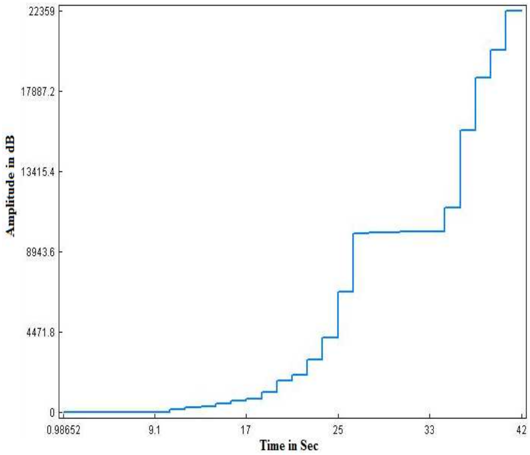




**Figure 7(a): Counts to Peak** **Figure 7(b): Rms**



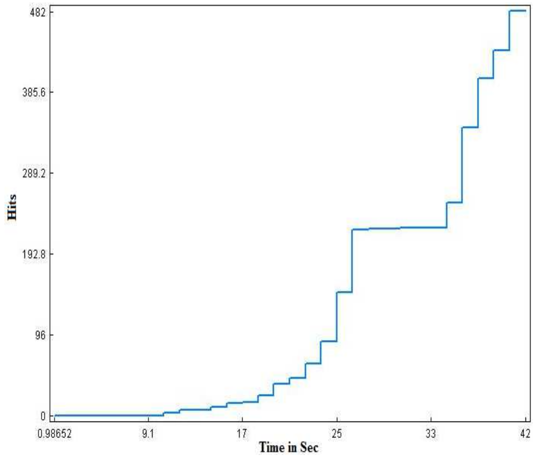
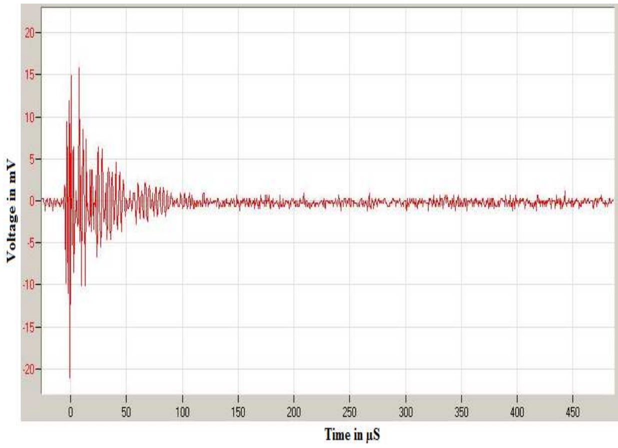




**Figure 7(c): Amplitude Figure 7(d): Hits**

**Figure 7: AE Parameters Verses Time for GFRP Laminate (After Aging)**

### AE Waveform Analysis

Typical AE waveforms pertaining to hit data and possibly related to the failure modes during tensile test monitoring are identified from the parametric analysis. Waveforms for GFRP specimen before and after strain aging are shown in Figure.7 & 8. From Figure observed GFRP laminate produced burst type AE waveform compare to conventional materials like Cu, Al, and steel. The reason for this burst type signal is mainly due to individual fibers breakage GFRP laminate [12]. From Figures also observed the low intensity of continuous type AE waveforms in after aging specimens compare to before aging this mainly due failure or fracture of specimens produce low-intensity continuous type signal compare yield stress level specimens produce high intensity more burst (discontinuous) type signal.



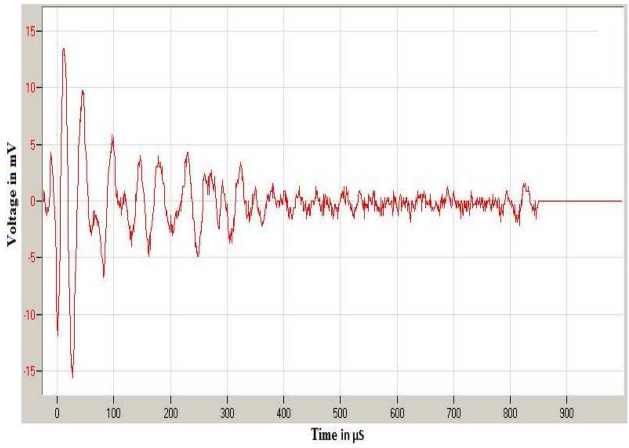




**Figure 7: GFRP AE Waveform before Aging Figure 8: GFRP AE Waveform after Aging**

## CONCLUSIONS

From the Acoustic emission signal monitoring during tensile test of GFRP, the following conclusions can be drawn.

- The breakdown or failure of Kaiser Effect on GFRP laminate identified by AE emission observed at loads lower than the previous maximum, especially when the material is in poor condition or close to failure. This breakdown or failure of the Kaiser effect was successfully used to predict failure loads in GFRP composite components.

- AE parameter of Counts to peak, AE Rms, Amplitude and AE Hits clearly in indicate different stages of initial loading, matrix micro-cracking and macro-cracking, fiber-matrix deboning and fiber failure during tensile testing GFRP laminate.
- The AE waveform of GFRP specimen found more burst type signal compare to homogeneous material like Al, Cu, and HCS. This mainly due to individual fibers breakage produces this type of signal like multi-phase material like GFRP.

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