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Conference paper

Damage Assessment of Sheet Molding Compound Composites

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ABSTRACT

The investigation focuses on the initiation and progression of damage in SMC (Sheet Moulding Compound) composites subjected to tension. These composites consist of a polyester matrix reinforced with randomly oriented short C glass fibers. Damage monitoring is conducted using the acoustic emission technique. To assess the influence of surface density on damage in SMC, three series of composites with surface concentrations of 300 g/m^2, 450 g/m^2, and 600 g/m^2 are tested. Based on stress-strain curves, the main mechanical properties of the different composites are determined. Additionally, the analysis of the collected acoustic emission data enabled us to determine the damage thresholds in the different studied composites. While tensile tests and the acoustic emission technique allowed us to determine important composite parameters, further research is necessary to comprehensively discern the various damage modes.

1. INTRODUCTION

Composite materials have made significant advancements in various applications recently, aiming to meet diverse requirements. However, these materials typically undergo degradation and aging due to external factors during service. Understanding the parameters influencing their resistance and lifespan is crucial. Therefore, efforts are directed towards enhancing their performance and refining their thermo-mechanical and physicochemical characteristics. For this purpose, several methods and techniques have been investigated [S. Tamboura et al., 2020], among these, the Acoustic Emission technique has had a significant impact in this field. The principle of the Acoustic Emission (AE) technique revolves around the detection and analysis of transient elastic waves emitted by materials when they undergo deformation or damage. When a material undergoes internal changes, such as crack initiation, propagation, or frictional motion, it releases stress waves. These stress waves produce acoustic emissions that can be detected by sensitive sensors placed on the surface of the material or nearby. By analysing the

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characteristics of these emitted acoustic signals, it is possible to gain insights into the condition of materials, including the presence and progression of damage. The AE technique is particularly useful for monitoring structural integrity in real-time, detecting flaws, and predicting potential failures. It is commonly used in various industries for nondestructive testing, structural health monitoring, and materials characterization

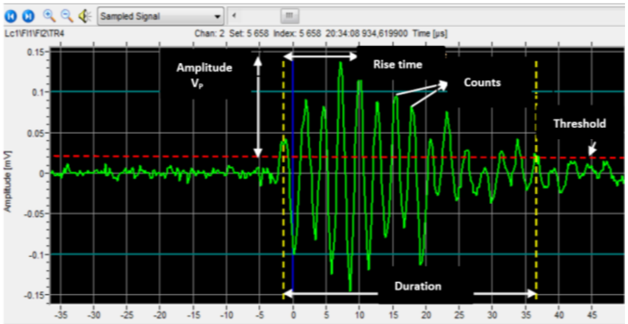

Figure 1. Diagram of a typical acoustic emission signal and its parameters

Where:

- E is the energy of the signal.
- Vp is the amplitude of the signal at the peak.
- t_1 is the time corresponding to the first threshold exceedance.
- t_2 is the time corresponding to the last threshold exceedance.

$$E = \int_{t_1}^{t_f} V_P^2 . dt \quad (1)$$

This study focuses on Sheet Molding Composite (SMC), consisting of polyester resin and glass fiber reinforcement. SMCs, known for their favorable mechanical and physical attributes, find widespread use across industries, notably in manufacturing wind turbine blades within the energy sector [Ali Khosrozadeh et al., 2017 and D. K. Kim et al., 2015]. SMC composites exhibit excellent durability and fatigue resistance, ensuring that wind turbine blades maintain their structural integrity over their operational lifespan, even under cyclic loading conditions. Overall, SMC composite wind turbine blades represent a promising solution for improving the performance, durability, and cost-effectiveness of wind energy. The present challenge then lies in constructing future energy conversion systems endowed with specific properties.

2. MATERIALS AND METHODOLOGY

2.1 Tensile tests

The studied material is the Sheet Molding Composite, containing unsaturated polyester resin and reinforced with randomly oriented type C glass fibers about 50 mm of length. This material is manufactured by the dry process using the molding compounds that are pre-impregnated for the manufacture of composite major releases: fabrics, roving, but mostly cut fiber. Three types of SMC materials with the following different surface compositions: 300 g/m², 450 g/m², and 600 g/m² were considered in this work. To evaluate the longitudinal Young's modulus for the material with the different surface mass, rectangular specimens measuring 250 mm in length and 25 mm in width were obtained from 2 mm thick plates using a diamond wheel saw. These specimens were then prepared for tensile testing. To prevent failure caused by stress concentration from the machine clamps, glass/epoxy composite tabs sized 40 x 25 x 5 mm were adhered to each end of the specimen. Tensile testing was conducted using a dynamic load on an Instron 4505 machine, which has a loading capacity of 100 kN. Three tests were performed for each of the three composites.

2.2 Damage monitoring using the Acoustic Emission technique

On the other hand, to analyse the initiation and development of damage within the various composites, the tensile testing machine was connected to the AE Vallen equipment. This AE system comprises two sensors, preamplifiers, and an acquisition card. The acquisition and processing of acoustic emission data are carried out using specific Vallen software on a PC. To ensure effective acoustic coupling, both sensor surfaces were coated with silicone grease and then attached to the two ends of the sample. Three tensile tests with AE recording were conducted for each composite.

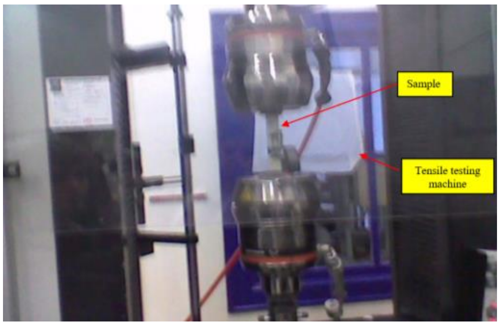

Figure 2. Tensile testing machine, Instron 4505

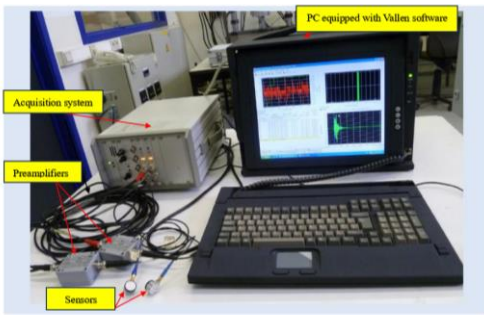

Figure 3. Acoustic emission equipment

3. RESULTS AND DISCUSSION

3.1 Stress-strain curves

Figure 4, shows the stress-strain curves for the three types of SMC composites. The stress-strain curves for SMC composites are characterised by two main regions. The first, linear region, relates to the elastic zone, followed by a non-linear portion. On the basis of these curves, the Young's moduli were calculated in the linear zone. Young's modulus E values and the main mechanical properties for the three types of SMC composites are shown in Table 1.

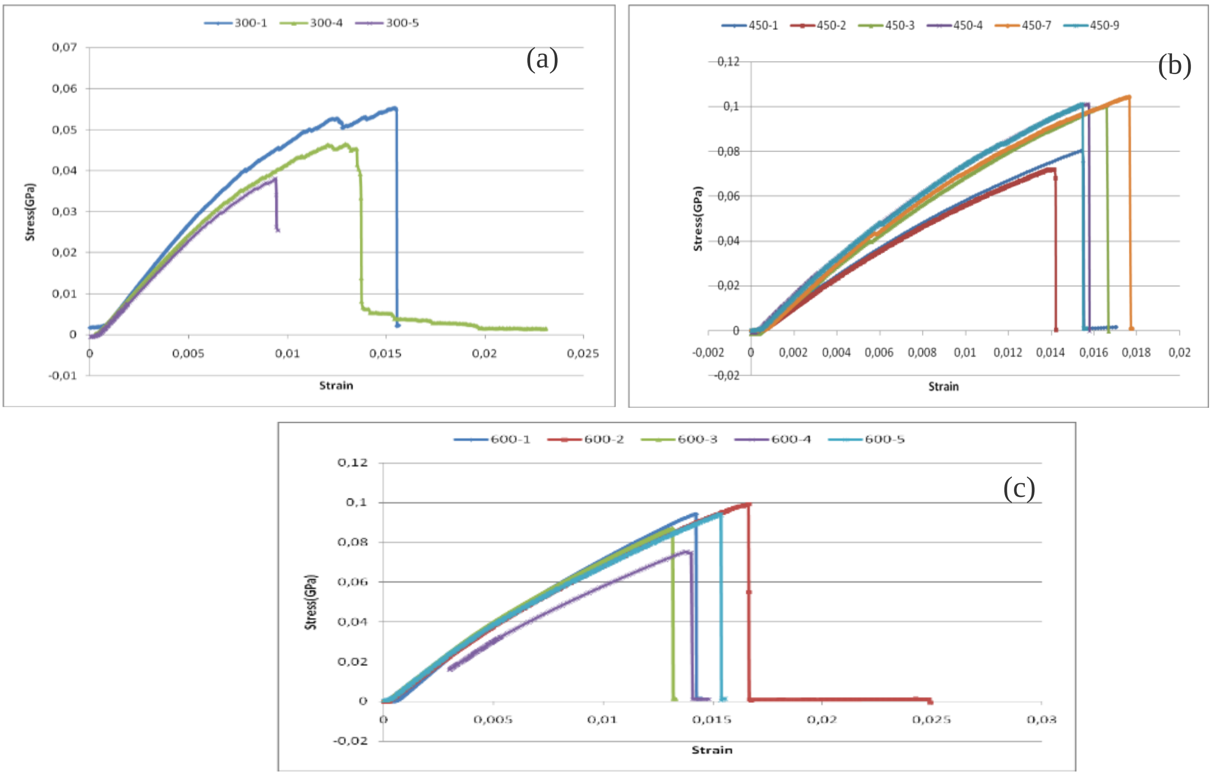

Figure 4. Stress-strain curves of the three SMC composites: (a) 300 g/m^2, (b) 450 g/m^2, and (c) 600 g/m^2

Table 1. Tensile tests results

Composite	SMC300 (g/m²)	SMC450 (g/m²)	SMC600 (g/m²)
Ultimate strength (MPa)	46 ± 8	100.43 ± 1.7	99.44 ± 0.24
Ultimate strain (%)	1.2 ± 0.3	1.57 ± 0.01	1.52 ± 0.15
E (GPa)	5.11 ± 0.25	8.38 ± 1.3	$8.36 \quad \pm 3.3$

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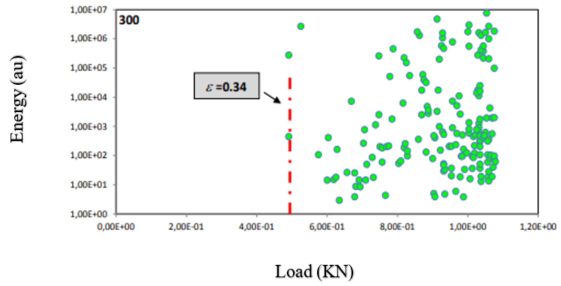
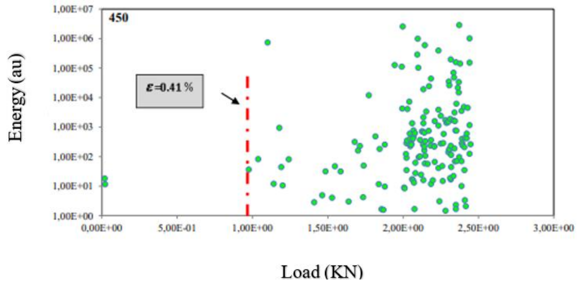
The different tests performed on each of the three composites, show a slight dispersion in the ultimate strength values between the different specimens. This dispersion is relatively greater in the case of composite SMC 300. This is probably due to the presence of porosities, which were well identified during optical microscopy analysis of SMC300. The observation of the stress-strain evolutions relative to the three SMCs with different surface compositions shows that these materials exhibit brittle behavior. The presence of mineral carbon and calcium fillers in these composites may cause their brittle behavior.

3.2 Acoustic emission results

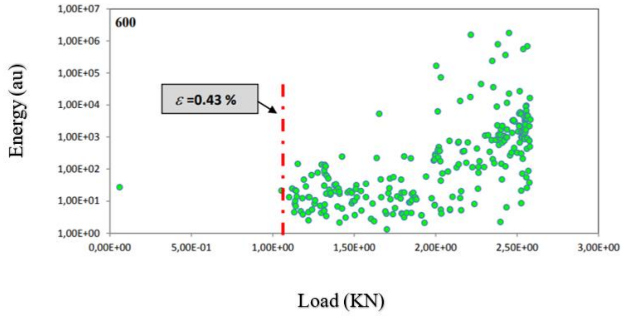
The energy and the cumulative energy emitted in the three composites are represented in Figure 5 and Figure 6.



(a)



(b)



(c)

Figure 5. Acoustic emission energy curves of the three SMC composites : (a) 300g/m^2, (b) 450g/m^2, and (c) 600g/m^2.

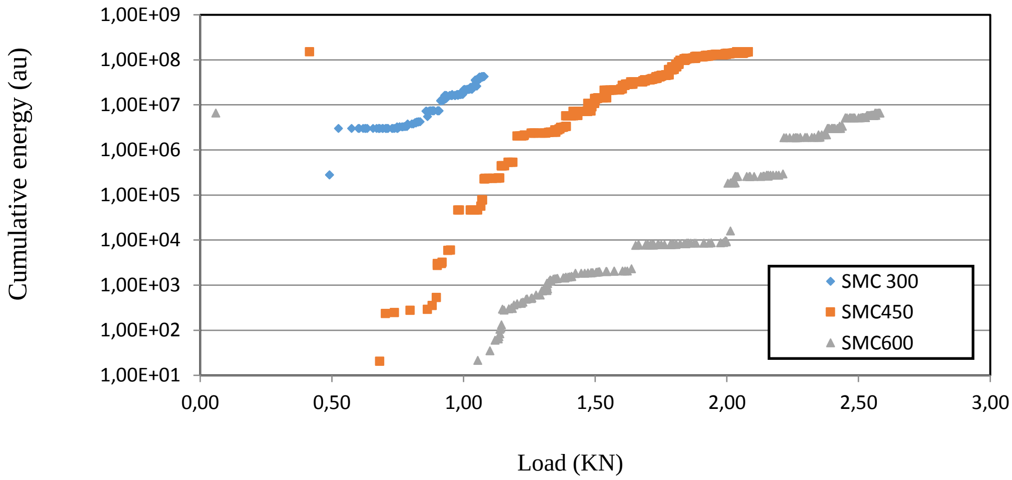


Figure 6. Graph summarizing the cumulative energy in the different composites

The combination between the stress-strain curves and acoustic emission results, allows us to determine the damage parameters. These main results are summarized in Table 2, as follows:

Table 2. AE results

Composite	Maximum AE energy (a.u.)	Damage threshold, strain (%)
SMC300 (g/m²)	10^7	$\varepsilon = 0.34$
SMC450 (g/m²)	10^6 - 10^7	$\varepsilon = 0.41$
SMC600 (g/m²)	10^6 - 10^7	$\varepsilon = 0.43$

The stress-strain curves allowed us to determine the ultimate stresses as well as the ultimate strains. The acoustic emission curves show that the cumulative number of events is significantly greater in the SMC450 material compared to SMC300 and SMC600. On the other hand, the analysis of the acoustic signals shows that the amplitude limit of the highest percentage of bursts does not exceed 70 dB in the SMC300 and SMC600 materials, while it reaches 90 dB in the SMC450. This suggests that in SMC450 composite, the fiber rupture damage mode may occur, unlike in the other two materials where the damage could be associated with other damage modes: Matrix cracking and Fiber/matrix decohesion [H. Nehad, doctoral thesis, 2004]. However, it is difficult to discern these damage modes due to the presence of overlapping zones, which makes it uncertain to attribute a signal to a damage that actually occurred [S. Choong Woo et al., 2007, and S. Tamboura, 2020]. Figure 6 shows that the energy starts by increasing slowly, remains linear for a certain period, and then increases rapidly; the energy dissipated in the SMC450 is significantly higher compared to the other two composites. It can also be observed that in SMC600, the cumulative energy shows sudden increases which could indicate a significant change in damage mode.

4. CONCLUSION

In this study, composite tensile tests were conducted to determine the mechanical properties and acoustic emission parameters. The analysis of mechanical properties provided valuable insights into the behavior of the composites under tensile stress, shedding light on their strength and durability characteristics.

Additionally, acoustic emission parameters were determined to monitor the internal structural changes and detect potential damage during the testing process. These parameters served as crucial indicators of material integrity and allowed for the identification of damage thresholds. Moving forward, further research can be conducted to complement these findings using other techniques to possibly gain a deeper understanding of the failure mechanisms within these composites, providing complementary insights to the mechanical and acoustic emission assessments conducted in this study. Overall, this study contributes to the comprehensive characterization of composite materials, enhancing our understanding of their mechanical behavior and paving the way for advancements in material design and engineering applications.

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