Advanced Failure Prediction in Composite Laminates via Acoustic Emission Techniques

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ABSTRACT
This paper work is carried out to predict the failure load of glass, kevlar and their hybrid composite laminates subjected to uni-axial tensile testing under acoustic emission monitoring. The specimens are subjected to uniaxial tensile test using INSTRON 3367 universal testing machine. The failure loads of the composite laminates can be effectively predicted with the help of artificial neural network tool available in matlab software. Three specimens each in glass, kevlar and hybrid are subjected to tensile load till failure occurs and the corresponding acoustic emission data are recorded using data acquisition software. Then one specimen each in glass, kevlar and hybrid is subjected to 50%, 75% of the failure load using which the failure load is predicted.

KEYWORDS: Acoustic Emission Monitoring, Artificial Neural Network, Online Health Monitoring.

INTRODUCTION
Development in engineering needs continuous research and modification. As with all engineering materials, composites have particular strengths and weaknesses. Composites are by no means the right material for every job. However, a major driving force behind the development of composites has been that the combination of the reinforcement and the matrix can be changed to meet the required final properties of a component. Composites can fail on the microscopic or macroscopic scale. Compression failures can occur at both the macro scale or at each individual reinforcing fiber in compression buckling. Tension failures can be net section failures of the part or degradation of the composite at a microscopic scale where one or more of the layers in the composite fail in tension of the matrix or failure of the bond between the matrix and fibers [5].

The dynamic behaviour of defects is extremely important as a small defect that is growing may well be more significant than a larger stable defect. Acoustic emission is the method used to investigate the behaviour of defects under stress. The test structure is subjected to a stress (usually slightly greater than the normal maximum load) by mechanical, pressure or thermal means. Under these conditions crack growth, local yielding and corrosion product fracture may occur resulting in a sudden release of energy, part of which will be converted to elastic waves. These elastic waves are readily detected by piezoelectric transducers which, by using methods of triangulation [6], can give positional information about the emitting defect. The amplitude of the received signals can also be used to give an indication of the rate of growth of the defect.

The idea of Artificial Neural Network [1] is based on the belief that working of human brain by making the right connections can be imitated using silicon and wires as living neurons and dendrites. The human brain is composed of 100 billion nerve cells called neurons. They are connected to other thousand cells by Axons. Stimuli from external environment or inputs from sensory organs are accepted by dendrites. These inputs create electric impulses, which quickly travel through the neural network. A neuron can then send the message to other neuron to handle the issue or does not send it forward.

ANNs are composed of multiple nodes, which imitate biological neurons of human brain. The neurons are connected by links and they interact with each other. The nodes can take input data and perform complex operations [2] on the data. The result of these operations is passed to other neurons. The output at each node is called its activation or node value. The computing system is made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs.

LAMINATE PREPARATION
Materials used for the preparation of laminates are glass fiber and kevlar fiber. Epoxy resin is used as the matrix material. The hardener is added to the resin in the ratio of 1:10.The specimens are prepared as per the ASTM D3039 standard. The dimension of the test specimen should be 280 mm×18 mm×4.28 mm. Totally 15 specimens are to be fabricated in glass, kevlar and hybrid laminates. All the specimens are made up of 12 layers. In hybrid laminates both glass fiber (6 layers) and kevlar fiber (6 layers) are arranged alternately.

The laminates are prepared using compression moulding machine and cured at room temperature at 100 bar pressure for 24 hours. After curing the specimens are prepared as per ASTM D3039 standard. Water jet cutting machine is used to cut the specimens in required dimensions from the laminate. The specimens are subjected to tensile test in INSTRON 3367 universal testing machine under acoustic emission monitoring using the 8-channel acoustics setup supplied by physical acoustics corporation [4].

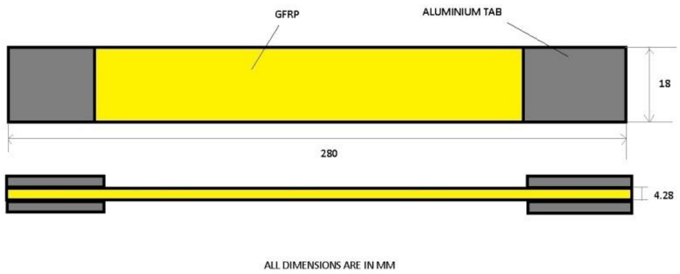

Figure: 1 ASTM D3039 Standard

MECHANICAL TESTING

Tensile testing is being carried out by INSTRON 3367 universal testing machine under acoustic emission monitoring using an eight-channeled acoustic emission setup supplied by Physical Acoustics Corporation. The specimens are mounted on the UTM machine and dimension of the specimen entered in the software. Three specimens each from glass fiber laminate, kevlar fiber laminate and hybrid laminate are loaded till failure and various acoustic emission wave parameters such as amplitude, count, energy, duration, rise time are recorded using the SAMOS E3.10 data acquisition system from Physical Acoustics Corporation (PAC), with a sampling rate of 3MSPS and a 40 dB pre-amplification[4]. These data is used for training the artificial neural networks. Also the failure loads for all the test specimens are to be recorded.

One specimen each from glass fiber laminate, kevlar fiber laminate and hybrid laminate are loaded up to 50% of its failure load. All the above said acoustic emission parameters are recorded up to this particular load and the specimen is further loaded till failure without recording the acoustic emission datas. The same procedure is repeated for 75% of the failure load.

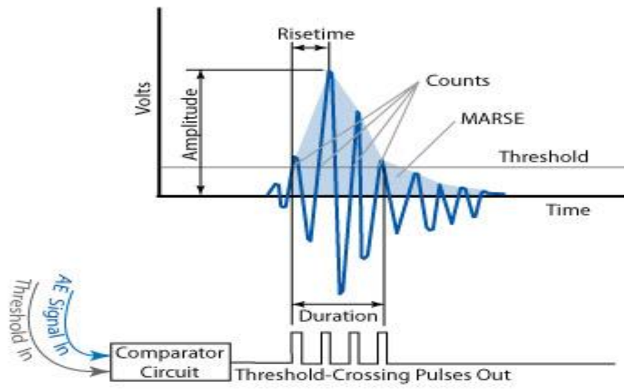

Figure: 2 characteristics of AE signal

ARTIFICIAL NEURAL NETWORK TRAINING

The failure load prediction was done using artificial neural network (ANN) with amplitude as the input parameter and the failure load as the target. MATLAB neural network toolbox was used for the prediction with network type self-organizing map [7] . The BP algorithm is most widely used learning procedure for neural networks because it is an error correcting algorithm, which calculates the error by comparing the calculated and target outputs. TRAINSCG and PURELIN were used as the training function and transfer function respectively. Five hidden layers containing 10 neurons in each layer was used for training the network [3]. The training parameters used were 30000 epochs. Simulation was carried out for the specimens that were not used for training the network. With this trained network failure load can be predicted for any similar specimen and it is found that the error is well within 15%.

RESULT & DISCUSSION

After the mechanical test, we have observed the following results. Also tabulated the predicted failure loads for 50% and 75% loads.

Specimen	Spec. No	Actual Failure Load (kN)
Glass	G_1	9.8
	G_2	10.5
	G_3	10.2
Kevlar	K_1	17.4
	K_2	17.7
	K_3	16.8
Hybrid	HY_1	13.8
	HY_2	14.1
	HY_3	13.5

Table 1. Tensile test failure loads

Specimen	Spec. No	Actual Failure Load (kN)	Predicted Failure Load (kN)	Error (%)
Glass	G_4	10.8	9.26	14.21
Kevlar	K_4	18.2	16.41	9.82
Hybrid	HY_4	16.9	15.43	8.59

Table 2. Predicted failure load for 50% loading

Specimen	Spec. No	Actual Failure Load (kN)	Predicted Failure Load (kN)	Error (%)
Glass	G_5	11.2	9.89	11.65
Kevlar	K_5	17.9	16.41	8.29
Hybrid	HY_5	14.6	13.17	9.74

Table 3. Predicted failure load for 75% loading

Specimen	**Spec. No**	**AMPLITUDE (dB)**				
		50-60	**60-70**	**70-80**	**80-90**	**90-100**
Glass	G_1	547	5846	6378	908	457
	G_2	649	6217	7302	735	592
	G_3	623	6063	6732	937	465
Kevlar	K_1	7384	78921	86103	12258	6170
	K_2	8762	83931	98577	9932	7992
	K_3	8421	81851	90885	12648	6278
Hybrid	HY_1	5578	59637	65076	9267	4667
	HY_2	6617	63413	74482	7496	6038

	HY_3	6356	61843	68667	9567	4745

Table 4. Analysis of AE data

CONCLUSION

This paper is able to predict the failure of laminates with the availability of 50% and 75% of the failure loads. However it is expected to predict the failure of laminates at a very early stage before the failure actually happens in the structure. This can be achieved by using online health monitoring system where the sensors are fixed permanently on the structure, which will be continuously feeding the acoustic emission data to the data acquisition system.

Furthermore number of specimens is to be tested until failure and their data should be stored separately so that the online health monitoring system will be always checking the incoming data with those available in the system memory. By doing so the cracks can be detected at the initial stage itself thereby preventing any structural failure.

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