ABSTRACT

In 1992 the author set out to gain a better understanding of the (then) current status of failure criteria for predicting the strength of continuous fibre polymer composites when subjected to multi-axial loading conditions. With the assistance and support of extremely dedicated colleagues (Sam Kaddour, Peter Soden, Paul Smith and Shuguang Li) the author has spent the last 21 years in pursuance of this mission. This simple curiosity had led to the organisation and coordination of the international activities, known as the ‘World Wide Failure Exercises’.

At the outset of this journey, the authors had given little thought as to how to ‘get at the truth’ regarding the level of maturity of the various failure theories in existence when deployed in real world design situations. Rather naively, the assumption was made that the originators of such theories were aiming to develop the tools that composite design engineers were desperate for in order to move away from the current dependence on ‘make and test’ (otherwise known as the building block approach). Extensive discussions with theoreticians, journal editors, composite designers and engineering software vendors revealed a much more complex landscape, characterised by a wide diversity in opinion on two critical philosophical points :-

(a) The definition of ‘failure’ of a composite, given their wide range of applicability in engineering 
(b) The attributes required by a failure theory such that it could be classed as ‘mature’.

With this as a backdrop, the first challenge faced by the authors was to devise a framework that would provide an objective, transparent and fair means of benchmarking the leading theories. The following key principles were employed to drive the thinking :-

1. The organisers of the exercise must maintain true independence from those participants making the predictions. (i.e. there must be no insider dealing).
2. Where predictions based on a given failure theory are required, the best approach is to request that the originator of the theory carries out the calculations. The room for misinterpretation by an intermediary is then removed.
3. A true comparison of theories should use a common set of test cases which are clearly and unambiguously defined. Equally, the parameters to be predicted should be clearly defined, so that direct comparison is
facilitated.

4. In order to determine the bounds on the validity of a given theory, it is important to test it over a wide range of conditions and to choose test problems which highlight the differences and similarities between the theories. Careful thought is needed, therefore, to identify the laminate and loading conditions which will test a theory to the full and thereby identify any discriminating features.

5. The test cases should not be chosen by those participants making the predictions, but by the organisers. In this way, the test cases are unlikely to favour any one theory.

6. There should be matching, high quality, experimental data available for each of the test cases to be analysed theoretically. Each theory can then be benchmarked directly against experimental observations. The debate can then be moved from whether theories (a) and (b) agree with each other, to which theory matches reality most closely and over what range.

7. The theoretical predictions should be made ‘blind’ in the first instance (i.e. with no knowledge of the equivalent experimental results). The participants should not be given sight of the experimental results for the test cases until all of the papers containing their predictions are complete and in the hands of the organisers. This avoids any suspicion of ‘tuning’ the predictions.

8. Whilst it is accepted that certain models can be ‘tuned’ to improve their accuracy, it is important to be able to discriminate between a ‘blind’ and a ‘tuned’ prediction. Clearly, in most design situations, the reliance will be placed on ‘blind’ predictions.

9. Comprehensive publicity would be an intrinsic part of the methodology in order to ensure that the information generated and the conclusions drawn would reach the widest audience and thereby have the greatest impact to move the subject forwards on a world basis.

The authors have applied these principles to conduct three benchmarking studies to date:-

World Wide Failure Exercise 1 (WWFE 1): Predicting the strength of laminates assembled from continuous fibre reinforced unidirectional laminae subjected to 2D in-plane loading [1].

World Wide Failure Exercise 2 (WWFE 2): Predicting the strength of laminates assembled from continuous fibre reinforced unidirectional laminae subjected to 3D loading [2], [3].

World Wide Failure Exercise 3 (WWFE 3): Damage, fracture and continuum mechanics theories for laminates assembled from continuous fibre reinforced unidirectional laminae [In Press].

The purpose of this lecture is to review the progress achieved to date, the work currently underway and the remaining challenges towards fulfilling the original objectives, and principles. In addition, the author will share the many lessons that have been learned, with the aim of encouraging others to carry out benchmarking activities in those areas of composites where a multiplicity of theories exist but with insufficient validation to have any credibility in the industrial world.

References

