EVALUATION OF THE MATERIAL PROPERTIES OF RESIN-IMPREGNATED NOMEX® PAPER AS BASIS FOR THE SIMULATION OF THE IMPACT BEHAVIOUR OF HONEYCOMB SANDWICH

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ABSTRACT

Driven by stringent weight saving requirements composite sandwich construction has evolved as one of the basic structural design concepts for load-carrying components of advanced aeroplanes and helicopters. Particularly, sandwich using laminated carbon fibre reinforced plastics (CFRP) as face sheets and NOMEX® honeycombs as core material is increasingly used due to features such as high strength-to-weight and stiffness-to-weight ratios as well as an excellent fatigue behaviour. While offering unique advantages, sandwich is also prone to a range of defects and damages. Due to the thin brittle skins and the weak core material CFRP sandwich structures are particularly susceptible to impact loading which may accidentally occur during assembly or operation of aircraft. Since these damages may have detrimental effects on the load carrying capability, they have to be considered in the damage tolerant design of aircraft structures. For that purpose it is necessary to determine the extent of damage in sandwich structures, resulting from impact events such as tool drop or thrown up debris. Up to now this task is mainly done experimentally by using drop weights to simulate the impact loading and NDT methods to determine the damage size. Since these experimental procedures are rather costly and time consuming, there is a clear need to supplement them by reliable numerical simulation tools. Usually, explicit finite element methods are employed for this task.

As far as the global behaviour of sandwich components is investigated by finite element methods it is sufficient to model the structure by using shell elements for the skins and solid elements for the core. In the case of honeycombs such models permit only a macro-mechanical description of the core behaviour. Thus, it is not possible to account for local failure modes of the hexagonal cell structure. Nevertheless, these local effects are important, if impact loading is investigated. For this kind of problem a detailed modelling of the honeycomb cell structure is required [1, 2].

Impact loading of honeycomb sandwich results in very complex damage modes in the core as can be seen in Figure 1a. For example, in the centre of the impact area the honeycomb material is crushed. This damage is mainly the result of local buckling of the cell walls and compressive failure of the resin-impregnated NOMEX paper. Closer to the edge of the impact area the core is subjected to high shear forces which results in shear cracks in the cell walls. This clearly shows that material properties such as stiffness and strength of the honeycomb material are crucial parameters for the formation of damage in the sandwich. Therefore, the knowledge of these properties are essential for a reliable numerical simulation of impact loaded honeycomb sandwich structures as shown in Figure 1b.

Usually, honeycomb manufacturers provide material data only for honeycomb blocks instead of the impregnated papers used as core material. So, one approach is to determine the paper properties from the global core properties. This can be done by numerical simulation of the tests used to measure the global properties [1]. This approach provides only averaged data and it is difficult to identify the non-linear behaviour of the material. Therefore, a research project was initiated which aimed at the determination of material properties of resin-impregnated NOMEX paper.

Two main problems had to be solved. The first one was to get sheets of impregnated paper with a sufficient size for testing. Since the hexagons of the honeycombs usually applied in aircraft structures are very small, it is not possible to cut test specimens directly from the cell walls. Therefore, larger sheets of NOMEX papers had to be produced by a honeycomb manufacturer. The applied process was similar to that used for the production of standard honeycomb cores.

The second problem was to find appropriate experimental methods. In a first move, standard test methods were evaluated [e.g. 3, 4, 5] which are normally used to determine material properties of paper and board. The result of this evaluation was that only the standard test for tensile properties [3] is applicable. Therefore, two new tests have been developed. The first one is used to measure the mechanical behaviour of impregnated NOMEX under compression (see Figure 2, left). It is based on the ring crush method of ISO 12192 which was modified to prevent premature buckling of the test specimen and to provide well defined clamping conditions. The second test fixture was designed for the determination of the behaviour of NOMEX paper under shear loading (see Figure 2, right). For this test fixture the concept of rail-shear tests was chosen and adapted to the special requirements of the thin-walled material.
These test procedures have been used to carry out an extensive test programme on NOMEX paper which was impregnated with phenol resin. Several parameters such as the paper thickness and the influence of the production process was investigated. One of the findings was that the impregnated paper has a distinct orthotropic behaviour. Another basic result was that the stress-strain relation depends strongly on the resin fraction. Whereas the plain paper shows a ductile behaviour, paper with a high resin fraction is rather brittle (see Figure 3). Further results of this study as well as details on the derivation of input data for the numerical simulation will be given in the paper. Additionally, some simulation results will be presented.

Figure 1 – a) impact damage of a NOMEX-honeycomb sandwich structure; b) numerical simulation of an impact on a NOMEX-honeycomb sandwich structure

Figure 2 – Test fixtures (left: compression test; right: shear test)

Figure 3 – Material characteristics of 0.08 mm thick NOMEX paper with different phenol resin volume fractions

REFERENCES