STRUCTURAL INTEGRITY OF ADVANCED COMPOSITES IN THE MACHINE INDUSTRY

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The application of advanced composites in design and economic aspects are discussed. Micromechanical approach is emphasized as an important level of analysis of composite materials. As a new example, a compressor piston is presented with reinforced ribs, the prototype was made from fibre - reinforced thermoplastics.

INTRODUCTION

The present paper describes several levels of structural integrity analysis of advanced composites, more specifically, it deals with micromechanical analysis.

As a product example a compressor piston with reinforced ribs is used, a prototype of which was made from fibre-reinforced thermoplastics.

Currently advanced composites are little used in the machine industry. The estimated composite volume of ca. 22 Mio US $/a in Fig. 5 is an approximation for 1995 (1). In fact this is not more than 1 or 2 % of Sulzer's total production volume of ca. 1.5 Billions US $/a. In spite of present limitations, advanced composites have opened up opportunities for creative engineers to find solutions to numerous problems. Also the composite industry can gain practical experience of developing new types of advanced composites in increasing but manageable volumes.

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Thermoplastic matrix composites will become even more important as soon as improved and economic industrial processes are available for their fabrication.

LEVELS OF STRUCTURAL INTEGRITY ANALYSIS

There are at least four distinct levels of analysis of composite materials of general interest. An overall structural analysis of the entire component is first necessary in order to obtain the local stress distributions due to the externally applied loadings. At this level, the laminated (heterogeneous) nature of the composite is not recognized, although the anisotropy may be considered, depending upon the rigorous approach used. This follows a standard engineering analysis, requiring minimal knowledge of the composite material response.

The structure can then be separated into individual subcomponents for a detailed stress analysis. Classical laminated anisotropic plate theory (or shell theory, if the body is curved) can be used, the boundary conditions being established based upon how this substructure is actually attached to the surrounding structure from which it is isolated for analysis purposes. This level of analysis predicts large deformations of the subcomponent, and the distribution of loadings. Here the individual plies of the composite laminate are not considered, except in determining the plate or shell stiffness required as input data.

Knowing the load distribution throughout the substructure, the stresses and strains at any point in individual plies can be determined using a point stress analysis. The element of material actually represents a point in the subcomponent, only the through-the-thickness geometry being preserved. At this level of analysis the specific layup construction of the laminate is recognised at the point of interest. The analysis predicts the midplane strain and curvature of the laminate at the point selected, the stiffness components of the laminate, and also the stresses within each ply. To do so, the point stress analysis requires as input data the stiffness and strength properties of the individual plies.

The ply properties can be determined experimentally, or they can be predicted using a micromechanics approach. A micromechanics analysis typically considers only the individual ply, using the known properties of the constituents (the fiber and matrix, and if applicable, the interphase) to predict the stiffness and strength properties of the ply. The analysis also provides a complete representation of the local stresses in the individual fibers and surrounding matrix material, and the stresses at the fiber-matrix interface. These are indicated in Figure 1. A crack initiation and propagation capability may also be available so that the progression of failure on the micro level can be predicted.

As suggested above, the four levels of analysis are interdependent in the sense that the output of one is used as input to the next. However, any one level of analysis can be performed totally independently of the others, provided the required input data are available, perhaps from experimental work. This is often the case, for example, when performing a point stress analysis. When the individual ply properties required as input have already been determined experimentally, a micromechanics analysis is not required. Alternatively, the micromechanics analysis may be used to supplement the experimental data, by providing values for those quantities not experimentally measured.

EXAMPLE: PISTON OF A COMPRESSOR

Figure 2 shows a piston of a compressor as a product example. A prototype piston was made from fibre-reinforced thermoplastics.

Figure 3 illustrates piston details, more specifically the design solution with reinforcement ribs.

The structural integrity analysis of the piston included Finite Element computations, however, only on the macromechanical and not on the micromechanical level.

Figure 4 compares the weight of the piston for the following choice of material: steel, aluminium and composite (CFK).

Finally, Figure 5 illustrates the estimated market for fibre-reinforced thermoplastics (1), however, for the year 1995.

CONCLUSIONS

Composites are in constant competition with other materials. When we consider "materials of the future", undoubtedly composites will take a prominent position.

In contrast to the past, when the different individual epochs in the history of the human race were distinctly characterised by the dominance of particular materials (stone, iron, copper), the second half of the 20th century can most appropriately be described as the age of divers materials.

REFERENCES

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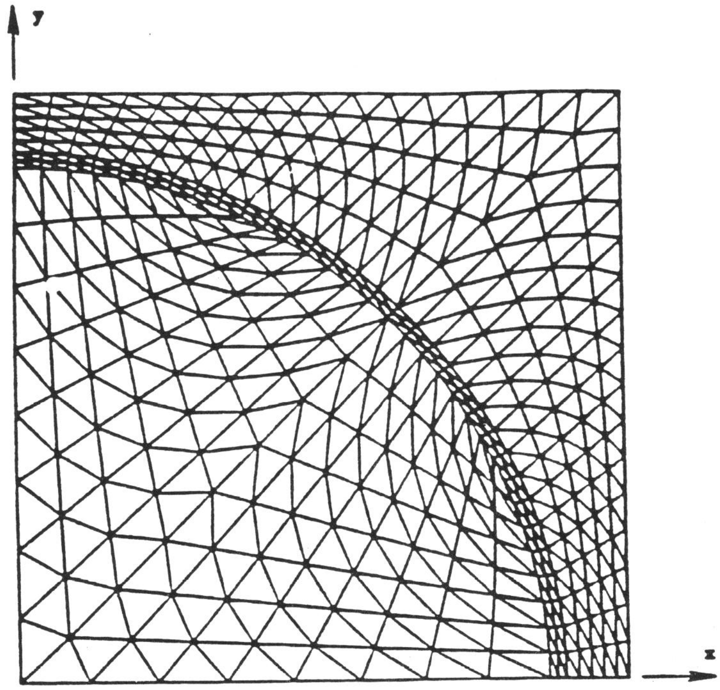

Figure 1 Micromechanical Finite Element Model of One Quadrant of the Repeating Unit Cell of a Unidirectional Composite Material; Square Fiber Packing Array. [WYO2D - The University of Wyoming's two-dimensional finite element micromechanics analysis acc. to (2)].

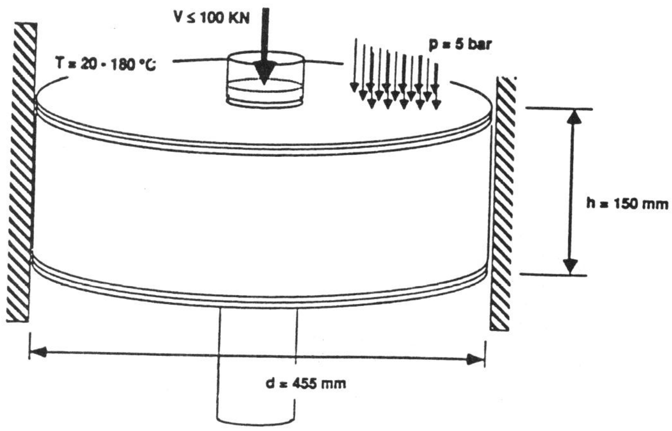

Figure 2 Piston of a compressor: dimensions and loading

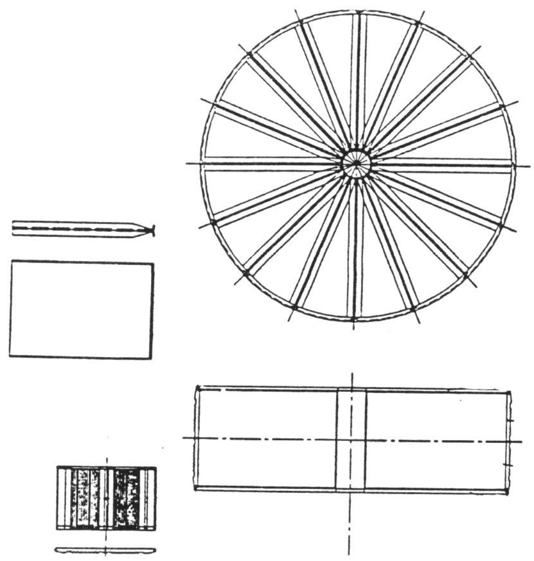

Figure 3 The piston with reinforcement-ribs

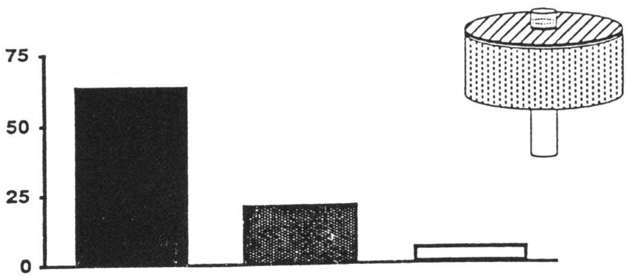

Figure 4 Weight comparison of the piston (steel, aluminium, CFK)

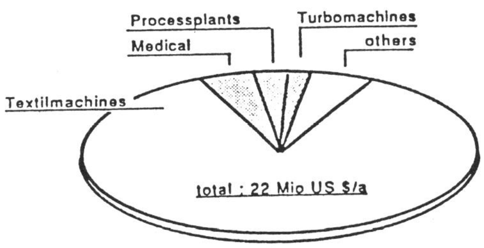

Figure 5 Estimated market for fibre-reinforced thermoplastics acc. to (1)