Name of the project: (2005-2007)

Development of integrated high performance composite joints and calculation methods for its design

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Characteristic of the project

Applications of composite performance parts are possible to find today not only in automotive and aerospace industry but even in production process industry and many others. The main advantage of these applications is high strength stiffness and low weight against standard alloy materials. The disadvantage of higher cost is decreasing every year thanks the rising volume of consumption of raw materials. The objective of the project is development of new breed of joints between composite parts and isotropic alloy part as a standard method of applying load to composite structures. The original technology of axial fiber winding will be used for joint development. The main principal of high performance integrated joints (HPIJ) in case of axial filament winding is that fiber tow is wrapped directly around the shape of alloy pin or tapered rod part. Main damage modes will be determined according to results of static and dynamic tests. Strain gauge and acoustic emission method will be used for IHPJ deformation monitoring. It will be the first time in Czech to verify the possibility of optical fiber sensors application and their integration to composite structures. Achieved results will be compared with classical adhesive joints. Damage models of composite joints will be verified by FEM numeric simulations. Another result of the project will be the concept of engineering models for integrated composite joints design.

State of the Art

Composite products are being increasingly used and are becoming an important class of engineering materials for a wide range of applications, such as the aerospace, athletic and recreational equipment, transportation, infrastructure, military, electronic and chemical industry. The reason that composite products find favor in people's eyes is based on the advantages of composites– lower weight, high stiffness, high strength, electrical conductivity, low thermal expansion, low or high rate of heat transfer, corrosion resistance, longer fatigue life, optimal design, reduced maintenance, fabrication to net shape, and retention of properties at high operating temperature.

There do exist many production composite technologies and its different variations. We will consider only these capable of production of so called performance product, product that must perform under some load, product that needs some analysis of its stress, or strain behavior. There do also exist many types of composites materials, but again we will consider more performance ones. One of these of our interests is the composite of long fibers and polymer matrixes [1].

All types of composites technologies need to have a mould, plug or mandrel. Against the surface of mold or mandrel is able to consolidate and cure liquid phase of matrix (resin) and fibers. Molding technologies is possible to sort for example by method of material lay-up: techniques like hand lay up, spraying or automated tape lay-up. Or it is possible to sort them by method of fiber impregnation: prepregs, resin transfer molding, vacuum assisted resin transfer molding, etc. We will focus only on the filament winding technology.

Filament winding, one of the most common techniques for the manufacture of closed profile products, provides the widest possibilities in the selection of types of layers during fabrication. In particular, the axial, circumferential and cross-winding layers can be wound where only the cross-winding layers encounter the problem of interlacing of fiber tows, which is a important feature of this kind of products. The interlacing should offer more defect resistant structures and, accordingly, there is the potential for greatly improved resistance to impact damage growth and delamination. The concept of the filament winding method is high-speed, precise lay down of continues reinforcement in pre-described patterns. It is a process, by which continuous resin impregnated reinforcements in the form of roving tows are wound over a rotating male mandrel (see Fig. 1).

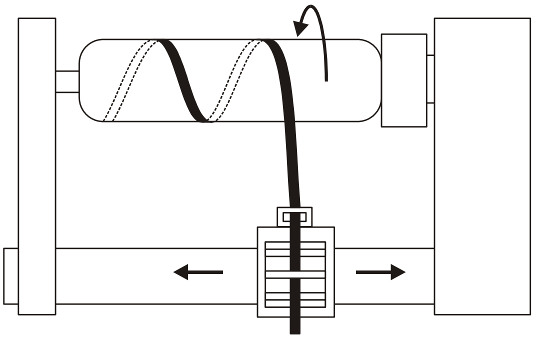


Fig. 1: Filament winding.

The technologies described above are resulting in different shapes. Products made by molding are usually thin walled shells or sandwich structures of typically very general shape. On other hand products made on mandrels are usually beams or tubes with closed cross-section dictated by shape of mandrel. These can be both thin and relatively thick walled structures.

The axial winding technology was developed by joint applicant, company Compo Tech PLUS Ltd. The original feature of this technology is possibility of axial fiber orientation (0 degree winding angle) allowing the significant increase of stiffness and strength of tubes with different profiles. Complete technology system including two CNC machines for concurrent winding of two tubes up to length of 8 meters (Fig. 2) were developed in Compo Tech PLUS Ltd.

Fig. 2: Winding machine developed in the Compo Tech PLUS Ltd. Company.

It is obvious that different resulting shape needs different method or model for structural analysis. To analyze a complex shape shell molded structure, the only solution is often finite element analysis (FEA), on other hand we can successfully analyze for example long beam with symmetric cross section by suitable analytic model [24]. But various parameters entering in to composite manufacturing method like different types of fibers patterns, their tensions, curing or laminate stacking sequences cause these analyses more complex and difficult than in case of conventional isotropic materials. In recent years, a lot of publications of considering above mentioned factors for calculation of stiffness, strain and strength were published by applicant and joint applicant see [3], [24], [25], [32] and [33].

The widely known problem of successful application of composite parts in to real structure is a joint between composite part and usually part from isotropic material. Isotropic material (steel and aluminum alloys) is often used for load implementation in to composite part or structure thanks its resistance to point load or thanks its wear resistance. There are generally three types of joints used in composite engineering: adhesive joint, bolted joint and so called integrated joint. The first two types of joints are most common in all kinds of applications and they were well studied and described years ago [47], [6]. Integrated joint is based on integrating function of part shape [44]. The principle of load transfer is than natural thorough the shape of parts generally directly in to fibers. There are many conceptions of integrated joints [5] and these differ usually by production technology applied.

Because a great experience of applicant and joint applicant [33] with filament winding technology several conception of integrated joints were proposed and preliminary studied (Fig. 3). The main principle in case of filament winding is that fiber tow is wrapped directly around the shape of alloy pin or tapered rod part (Fig. 3a). By this method load is implemented directly in to composite structure avoiding cutting fiber or adhesive shear load, fiber tow is directly loaded and high performance in strength and fatigue can be achieved, that why joint is called high performance integrated joint, further IHPJ. The first experiences from studies realized by of applicant and joint applicant [3] showed the possibility of development of optimized joints for tensile load transmission (Fig. 3b – fibers' dominant orientation of 0°) and torsion transmission (Fig. 3c – fibers' dominant orientation of 45°)

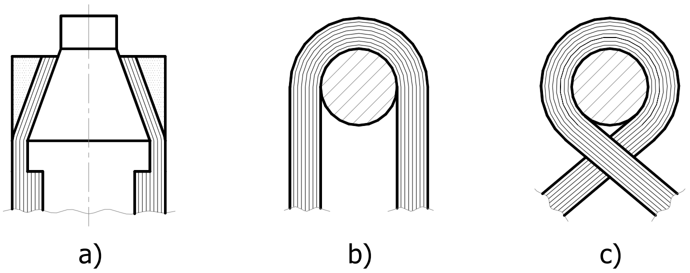


Fig. 3: Examples of integrated joints conceptions.

The conception of application of IHPJ in to composite structure is based on implementation of whole number of for example smaller diameter pins or respectively pin holes in case of composite structure (Fig. 4).

Fig 4: Integrated wound in "pin joint", Compo Tech hydraulic cylinder sample, after break test.

For deformation analysis and damage process of composite joint, it is important to apply the methods of deformation measuring and failure detection. Resistance strain gauges are commonly used. Recently, strain measurement methods based on Fibre Optic Sensors (FOS), Fibre Bragg Grating, has started to be used worldwide in different applications; [34], [35], [36], [37] and [38]. Application of the FOS sensors to the composite structures enables their integration to the composite part-joint during production phase and it will enable following measurement of working deformations inside of composite structure or respectively between its layers or fiber tows. The method of strain measurement based on FOS has not been realized in the Czech Republic so far. Application of this method directly to designed joints and tests of its utilization to for failure identification in service are assumed in the project.

Then acoustic emission, sonography and other methods are used for determining of damage modes. There is very well equipped laboratory of Institute of Thermomechanics of Academy of Sciences of the Czech Republic. Cooperation with this institute is assumed.

There are a lot of commercial FEM programs that can be used for analysis of stiffness and stress in composite structures. Modeling of joints is more demanding when respecting different influences of e.g. adhesive layer, surface contact and nonlinearity of deformations and stresses, see e.g. [45]. Verification of FEM calculation methods according to test results must be considered. In design praxis, there is a need for simple and fast calculation models. There were only very few studies published on topic IHPJ computation models and its experimental verifications, e.g. [44].

Project targets

1. Development of new generation high performance joint between composite structure and other mechanical parts, so called integrated high performance joint (IHPJ). Main principle of such joint is implementation of filament winding technique; fibres are loaded directly not thorough adhesive shear joint.

2. Development of engineering design procedure of IHPJ based on damage model of static and dynamic fatigue load. Damage model will be based on application of analytical methods.

3. Verification of damage model of IHPJ will be provided by both numerical (FEM) analysis as well as complex experimental program.

4. Application of Fibre Optic Sensors (FOS), Fibre Bragg Grating, in to composite structure during technological process of fibre winding for purpose of strain measurement during experimental verification program. Proposal of fatigue load and damage monitoring of composite structure during real operation life based on FOS measurement.

Conceptual and methodical approach

Strategy of development can be described as in following scheme. Diagram of activities and method of solution are divided to three main areas. In the first area there is application of developed and well-established technology of composite structure filament winding. The technology will be used for production of test samples at joint-applicant (Compo Tech PLUS Ltd.) factory. Technology has to be effectively set up to appropriate joint including the software for winding control. New approaches of technology adaptation for winding of composite structure’s joints with complex shapes will be developed.

The key part of IHPJ development is method used for second block of diagram bellow. Performance of newly designed IHPJ and their calculation methods will be compared with existing adhesive joints. As mentioned earlier, new generation of adhesive will be used for comparing samples. Static and dynamic tests (with harmonic loading) will be performed for several types of IHPJ. IHPJ pin joints will be tested for transmission of tensile stress (predominating fibre angle of 0°) and transmission of torsion (predominating fibre angle of 45°). Third type of IHPJ joints is wound-in taper insert (Fig. 3a). Modes of failure (static and dynamic) will be monitored during tests using acoustic emission method (in cooperation with Institute of Thermomechanics of AS CR) and experimental stress analysis (ESA).

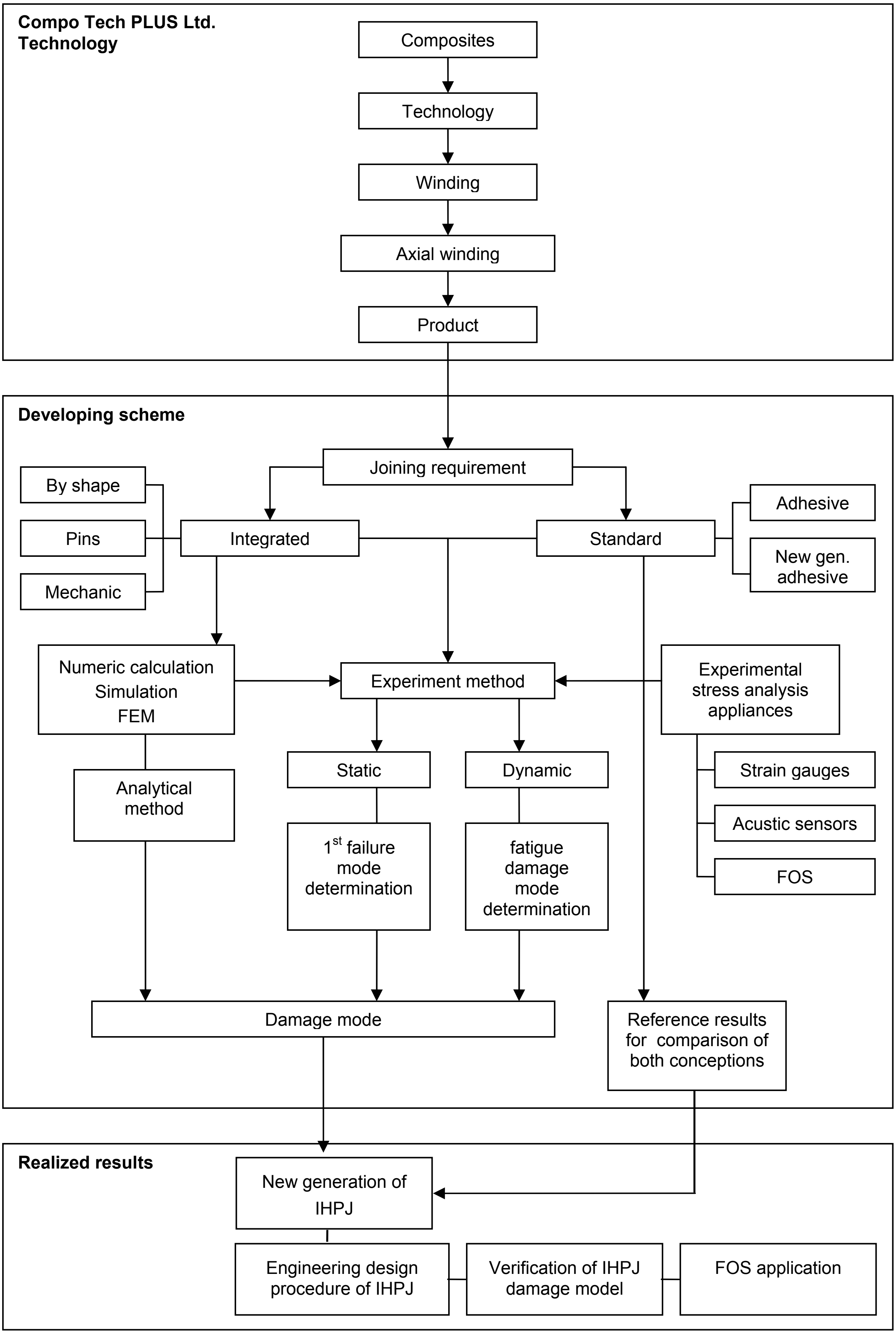
Expected outcomes of the projects

1. Three types of IHPJ will be developed: "single pin" IHPJ for bearing the tension load, "single pin" IHPJ for bearing the torsion/shear load and "tapered shape" IHPJ for bearing tension/compression load. Joints can be integrated directly to many real highly loaded engineering structural parts. Examples of standard adhesive joints will be examined to compare advantages of IHPJ solution.

2. IHPJ damage model written in computer code will be developed. It will be based on analytical expression of stress/strain analysis and applications of suitable criterions of static and fatigue failure. Outcomes of proposed IHPJ damage model computer code will be parameters, which will be possible easily, implement to existing engineering design procedures.

3. Numerical (FEA) simulation of different shape/load specification will be proceeded. Based on this simulation suitable shape/load versions will be chosen for experimental program. Experiments will verify both static and dynamic damage model behaviour of different IHPJ versions.

4. Application of FOS in technological process of fibre winding will be developed and evaluated. Strain measurement of IHPJ using FOS will be realised. Both strain gauge and FOS data will be used for damage model verification. Implementation of FOS directly in to composite structure will find its advantages in wide range of application in both load and fatigue damage monitoring.


Compo Tech PLUS Ltd.
Technology
Composites
Technology
Winding
Axial winding
Product
Developing scheme
Joining requirement
By shape
Pins
Mechanic
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Adhesive
New gen. adhesive
Numeric calculation Simulation FEM
Experiment method
Experimental stress analysis appliances
Static
Dynamic
Strain gauges
Acustic sensors
FOS
Analytical method
1st failure mode determination
fatigue damage mode determination
Damage mode
Reference results for comparison of both conceptions
Realized results
New generation of IHPJ
Engineering design procedure of IHPJ
Verification of IHPJ damage model
FOS application

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