What is Pultrusion

Pultrusion1. Introduction / Historical background Pultrusion is one of the oldest processes for the manufacture of long fibre reinforced thermosetting plastics, and it is also the oldest continuous processing technique. As early as 1954, W. B. Goldworthy, one of the pioneers of the fibre composite technique, presented a detailed description of the pertinent process and plant engineering principles to professional circles in the USA. This approach was largely employed to make profiles for uniaxial stress used, for instance, for fishing rods, ski poles, hammer handles, poles for vaulting, etc. Other countries, too, started to utilise the high tensile strength of glass fibres for pultruded profiles in the 50s. In this context, vertical pultrusion techniques targeted specifically for complex profile cross-sections, primarily hollow profiles, were developed in addition to the horizontal approach, where the fibre feed around a centrically suspended core was less problematic than with the horizontal approach. Thus, a wide range of profile cross-sections was available even in the 1960s (Fig. 1 and 2).

This process has experienced considerable diversification over the years in order to extend the property profile; today, a variety of profiles are available for a number of purposes, both with regard to the dimensions of the profiles as well as the complexity of the reinforcing structure. In 1960 there were about 20 manufacturers all in all, located primarily in the United States; while today at least 90 pultruders are serving the main markets in the USA, Europe, and the Far East. The market volume in Europe alone reaches an estimated 16,000 tons p/a. 2. Technical principles Pultrusion is a continuous process for the manufacture of profiles. Depending on the required strength, a variety of reinforcing materials (roving, mats, fabrics, complexes, non-woven fabrics) may be reeled off coils and rolls and fed into the mould. Using hydraulic clamps or other take-off units, the reinforcing materials are then pulled through a mould matching the geometry of the desired profile. The reinforcing materials are accurately guided in front of the mould and are impregnated with the matrix (resin, fillers, additives) in a bath respectively by injection in the mould. The matrix in the mould is then cured by heating. Curing

The resin-impregnated reinforcing materials, when entering the mould feed section, are transversely compressed and heated up to 160 °C inside the mould, depending on the used resin system. The exothermic cross-linking reaction (curing) starts as soon as the peroxide decomposition temperature is reached, and it proceeds from the mould surfaces to the centre of the profile (Fig. 3).

The resin gells and cures, causing high forces of friction along the mould wall and – in the case of hollow profiles - along the mandrels, too. The continuous roving strands, oriented in longitudinal direction, absorb the required high take-off forces. Mould release agents are introduced into the matrix in order to reduce friction forces.Cooling sections in the feed zone of the mould are to keep temperatures down in pultrusion direction so as to avoid premature matrix curing (Fig. 4).

The moulds are electrically heated. Sensors, introduced into various different mould sections, afford precise information about the temperature curves in the individual zones. If the actually reached temperatures are known, then the take-off speed may be optimised between 0.02 and 3 m/min.Take-off

The continuous process is ensured using caterpillar take-off units or hydraulic clamps, which may be operated individually, jointly, or parallel. Take-off forces of 6000 kg and more can thus be attained.

Process speeds may vary considerably, depending on the wall thickness, the reinforcing structure, and the complexity of the cross-section; values between 0.02 and 3.0 m/min may be reached. Values of 20 m/min may be attained with thermoplastic matrices. 3. Equipment Equipment includes warp creels and suspensions for two-dimensional reinforcing materials, impregnating units with a variety of auxiliary impregnating equipment, guide elements to feed the reinforcements into the pultrusion moulds, as well as a variety of take-off elements and sawing devices. Specific technical know-how with regard to individual plants is reflected in the respective equipment design and lay-out. Several of these plants are charted below. Yet there are comparatively few plants being offered; most of the plants used in this context were constructed by the respective profile manufacturers themselves.

Pultrusion units - moulds

Pultrusion moulds made of high-alloy steels are approximately 0.75 to 1.5 m long; their width and height correspond to the profile cross-sections and are subdivided into several sections. The interior is frequently polished and chrome plated in order to ensure low frictional resistance and good surface quality.

4. Raw materialsA wide variety of thermosetting and thermoplastic resin systems are available for pultrusion. Heading the list are unsaturated vinyl ester-, epoxy-, unsaturated polyester-, and phenol-resins as well as methacrylate resins (due to optimum halogen-free flame retardant properties); plus various thermoplastics.

Unsaturated polyester resin (UP)

Special types of this resin system are used for pultrusion. Due to their viscosity, they are easy to fill with kaolin, chalk, aluminium trihydrate (ATH) or ammonium polyphosphate (APP).

Methacrylate resin

Four to five different methacrylate resin types are available. They have the following advantages over normal polyester resin types:

- High filler content with ATH up to 200 parts (complies with the most stringent fire safety standards)
- extremely effective flame retardancy if ATH & APP are added
- high reactivity (relatively high pultrusion speed)

- low shrinkage (good-quality surface, no exothermic cracks)
- easy to be pigmented Phenol resins

Phenol resins are the oldest known resin systems; they are created by condensation of phenols and formaldehyde. Due to water releasing there is a danger of cracks and pores during the curing process. This may cause considerable processing problems. Very low flammability, but high flue gas emissions. No pigmentability.

Thermoplastics

Combinations of glass fibres and thermoplastics are another option to improve specific properties such as surface slip characteristics, subsequent deformation during heat exposure, abrasion resistance, and chemical stability. Polyethylenes, polypropylenes, and polyamides are primarily used as matrix materials. Reinforcing fibres
Glass and carbon fibres (in specific cases also aramide fibres) largely determine the strength and the rigidity of the resulting profiles.

Glass fibre reinforcements

Glass filaments of the E, C, or S glass types, bundled by melt spinning to form rovings with a weight between 600 and 9600 tex, form a unidirectional reinforcement in pultrusion direction and are mostly an important part of the reinforcing structure. The filaments are surrounded by a silane size considerably enhancing cross-linking with the matrix (adhesion). Three types are used for pultrusion: smooth roving, textured roving, and monofilament roving. With the latter, increased transverse strength may be achieved despite the unidirectional arrangement.

Continuous filament mats

Continuous filament mats (CFM) with a multiaxial arrangement of bonded or needled glass filaments are used primarily for the reinforcement of the surfaces of extensive profiles, with high demands regarding the surface finish (low roughness and porosity). Mat weights of 300, 450, and 600 g/m² are available.

Surface mats

Polyester or glass mats form an overlay on many profiles, affording high-quality closed surfaces and largely determining the weatherability and UV resistance as well as the colourfastness and the chemical resistance, because profiles usually are not painted. Weight categories are between 30 and 100 g/m².Woven fabrics / non-woven fabrics
These reinforcing materials may be used to increase the transverse strength. Fibre combinations in the 0°, 45°, and 90° direction, but also non-woven hybrid fabrics (such as glass / carbon fibre) with different layers are produced, for instance with a roving beneath and a 0°/90° mat on top, or with a mat below and a continuous filament mat on top to attain resin rich and therefore smooth surfaces.

Flame retardant mats

Flame retardant mats at the surface, such as graphite mats, make standard polyester resins with a low filler content to comply with the DIN 5510 S4 norm, because they foam in case of fire, thus keeping the oxygen away from the source of the fire (at 160 °C, graphite fibres will expand by a factor of 9).5. Design parameters Almost any profile cross-section can be manufactured with the following parameters:

- Max. length 12 m (transport)
- Max. width 1350 mm / 900 mm, depending on the flammability rating
- Wall thickness at least 1.5 mm, normally 3 – 3.5 mm, max. 60 mm (avoiding extreme abrupt changes in wall thickness)
- Colours basically according to RAL, homogeneous pigmentation only possible to a limited extent (glass has no pigment tolerance)
- Undercuts are possible
- Different wall thicknesses are possible
- Hollow profiles are possible (mind the variations in wall thickness tolerance due to the floating mandrel)
- Radii between 0.5 and 2 mm are required

Information regarding the dimensions of the individual profiles are given by the manufacturer. 6. Properties GRP profiles have an anisotropic structure. Depending on the laminate structure, the mechanical properties are listed in Table 1
Density 1,65 – 2,15 g/cm³Flexural strengthlongitudinal440 / 500 N/mm²Flexural strengthtransversal200 / 300 N/mm²Flexural modulus of elasticitylongitudinal17500 / 25000 N/mm²Flexural modulus of elasticitytransversal12000/ 17000 N/mm²Compression strengthtransversal240 / 350 N/mm²Tensile strengthlongitudinal430 / 900 N/mm²Tensile strengthtransversal60 / 200 N/mm²Elongation at breaklongitudinal2,2 %Elongation at breaktransversal1,6 %Coefficient of expansion 1,5-5 x 10^-6xK^-1Water absorption 1,16 / 2,5 %Table 1

7. Flammability ratings The following flammability ratings were achieved at a minimum wall thickness of 3 to > 5 mm:
- DIN 5510 S4 SR2 ST2
- DIN 4102 B2 / B1
- NF F 16101 M1/F0
- UL94V0
- ASTM E 162
- ASTM E 662
- BS 7239
- BS 476 – Pt.7 1997: Cl 1 (0)
- BS 476 – Pt.6 1 B
- BS 6853 – 1999 D 8,4: 4,76/4,87 on/off (2,2/2,5)   8. Standardisation The following standards are available regarding the manufacture, quality determination, and quality assurance:
- PrEN 13706 General European specifications for pultruded profiles
- DIN 18820 Reinforced laminates for load-bearing building components
- DIN 2768 Free dimensional tolerances
- ISO 178 / ISO 527 / ISO 604 / ISO 1183 / ISO R62
- IEC 93 & 112 Formal test specifications for material testing 9. Fabrication (see also Chapter 4)- Profiles are treated primarily using diamond-studded tools.
- Drilling, sawing, milling, grinding with conventional hardened tools
- Glueing / bonding
- Painting / coating / foil glueing
- Screwing with / without self-tapping inserts (Ensat)

Examples of applications
- Vehicle construction / thermal insulation (Fig. 8)
- Railway technology (Fig. 9 and 15)
- Cable ducting (Fig. 10)
- Wastewater treatment plant covers (Fig. 11)
- Medical technology (Fig. 12)
- Satellite technology (Fig. 13)
- Lattice masts for airports (Fig. 14)
- Construction profiles (Fig. 16)
- Antenna engineering (Fig. 17)
- Sporting goods, fishing rods,
- External planking, benches
- Bracings / round rods for live cables
- Profiles for parapets and stairways
- Gratings, profiles for ladders

- Hammer handles resonators for xylophones
- Lamp profiles
- Strain relief elements (with a thermoplastic matrix)