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Technical Note

The use of carbon fibres in radiotherapy

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Summary

In this paper we discuss some of the properties of carbon fibres. Use can be made of this strong, rigid and light material for applications during radiotherapy. Some processing methods and a short description of some accessories made of carbon fibre, which are in clinical use in our department, are given.

Introduction

Due to their good mechanical properties combined with a low specific density, carbon fibres have already been used for many years in the space and aviation industries. The high costs of these materials limited their use on a large scale. Recently carbon fibres have been applied for the construction of various sporting articles. For this application the production increased considerably while at the same time the costs of carbon fibres sharply decreased. This strong price reduction made applications in other fields such as diagnostic radiology [1] and radiotherapy possible.

For the manufacturing of accessories needed during patient treatment by means of radiotherapy, an urgent need for a strong, rigid and especially light construction material exists. That need became apparent in 1987 when we had to design a very rigid box for the housing of a portal imaging device, developed in our Institute [2]. Originally we made a box of steel which was difficult to handle in clinical practice due to its heavy weight. The use of carbon composite materials resulted in a very light and rigid box with a cassette-like shape for the portal imaging device. This yielded a weight difference of 10 kg compared with the first design made of steel (15 kg). It became clear that carbon fibres in combination with other materials, such as magnesium, aluminium and suitable kinds of cement, could become a very promising material for use in radiotherapy.

It is the purpose of this paper to describe some properties and processing methods of applications of carbon fibres in a radiotherapy department.

Materials

Technical background and processing methods

Carbon fibres are produced by allowing organic fibres such as cellulose and polyacrylonitrile (PAN) to undergo a three-phase heating process under mechanical stress in a pure oxygen or inert atmosphere. After the last heating stage the percentage carbon of the fibre varies between 95 and 99%.

The most frequently supplied forms of carbon fibre are mats, tubular braidings and prepregs. Mats are woven out of tows of carbon fibre. These mats are woven in different patterns, depending on the direction in which the product will be strained (see Fig. 1). We also use hybrid fabrics which combine other materials such as glass, aramide and polyethylene fibres with carbon fibres.

Tubular braidings are made of fibres strung together in tubular forms by use of specialised knitting machines (see Fig. 1). The relationship between the mechanical properties and the weight of the composite depends on the direction in which the product will be strained and therefore on the angle the fibres mutually make.

Prepregs are fibres which already have been impregnated with epoxy resin. This epoxy resin is partly cured. These braidings have to be stored at a temperature of $-18\,^{\circ}C$. In this phase the fibres are still movable. The ultimate curing will take place after moulding at a higher temperature. An advantage of this form of fibres is that they always have the correct ratio between the weight percentage of fibres and epoxy resin.

Properties of carbon fibres

The composite is made of a matrix of epoxy resin and carbon fibres. The purpose of the matrix is to protect and bind the fibres and take care of the strain transfer. The tensile strength of the fibres can be 10 times higher than that of aluminium and equivalent to the value of high grade steel. The rigidity is equal to or higher than that of steel. Its specific density of 1.8 g/cm^3 is, however, much lower than that of steel (7.8 g/cm^3) or aluminium (2.8 g/cm^3). Carbon fibres have a maximum tensile strength and rigidity in the direction of the long axis of the fibres and are relatively weak in the direction perpendicular to it. Carbon fibres can therefore not simply be compared with materials like aluminium and steel which have equal properties in

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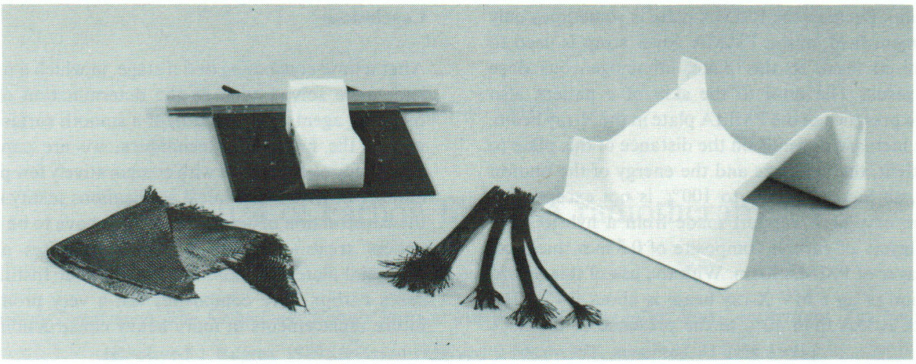

Two forms of carbon fibre, mat and braiding, and two examples of accessories made of carbon fibre: an adjustable neck support and a patient head support used on a CT-scanner.

all directions. If a design for a fibre construction is made, we first have to define in which direction the strain will be applied, so the proper fibre orientation can be provided when cutting the fibre mat. The poor properties perpendicular to the long axis of the fibres will make the composite brittle and give it a bad impact resistance. These properties can be improved by using a hybrid fabric, like carbon with aramide or carbon with polyethylene.

Processing methods

In a radiotherapy department the production of accessories is usually limited to simple items and small series. Therefore, we always try to use a simple working technique. There are several ways for processing the fibres, but the best result is obtained by using a simple, closely fitting hot mould which consists of two parts. This method gives optimum mechanical properties, a good fibre-resin proportion and good surface conditions. Flat sandwich panels are generally not constructed by means of a mould, but require a vacuum-forming method. For this method we need a vacuum-working table, which can be heated to approximately 50 °C and a vacuum pump. The method will be discussed in the following example describing the construction of a carbon fibre sheet for patient support. For this application two carbon fibre plies are separated by a sheet of polymethylmethacrylate (PMMA) foam. PMMA foam is used because this material has very little compressibility and has a very low specific density of 0.07 g/cm^3. This method of construction results in very good mechanical properties. Firstly, the fibres and the PMMA foam are cut into the desired dimensions, the bottom and top glassplate are coated with a releasing agent and the first layer of resin is applied on the bottom glassplate. On this resin we place the first carbon fibre ply and impregnate the mat with epoxy resin.

The required amount of mats are build up and the PMMA foam sheet is positioned. On top of the foam sheet the carbon top layers are placed and impregnated. When the impregnation of the fibres is finished, the top glassplate is placed on top of the hybrid. In between these two glassplates some structures are placed to support the glassplates and to provide the right spacing between the two glassplates. Then the table is covered with a PVC foil and this foil is sealed onto tape on the outside of the table. Next the vacuum pump is switched on to provide a vacuum underneath the foil. After approximately 8 h the resin is cured and the product can be released and finished.

Sometimes a connection between carbon composites and another material, for instance aluminium, is required. For this purpose an aluminium or plastic plug is positioned in the PMMA foam at the place where a screwed connection has to be made later. With suitable adhesives it is further possible to connect various metals and plastics to carbon fibre products.

Examples of accessories made from carbon fibre

After the megavolt imaging device, a number of accessories was made in our department using carbon fibres or a combination of carbon fibres and light alloys, plastics or glass fibre/aluminium honeycomb panels. These include the following:

Patient support
A patient support sheet has been made of carbon composite material and PMMA foam as described before. We use this sheet to support patients on the treatment table instead of a patient support board made of wood.

Table support
As support for the PETP (thermoplastic polyester) foil for the AP-PA treatment in the pelvic region, we use a hybrid plate on the treatment table. The patient positioning as done on the simulator couch, which has a flat wooden patient support, can therefore be reproduced with higher precision. The hybrid plate does not disturb the dose distribution.

Table hatch
An I-shaped table hatch stretched with PETP foil was made. Due to the construction and shape of this hatch it is possible to support the patient during treatment under certain gantry angles and to avoid material of the table hatch construction in the radiation field. There are strict requirements for the construction of such an I-shaped table hatch because of the great tension caused by the stretched PETP foil and the weight of the patient. Due to these requirements, this hatch, if made of conventional materials such as aluminium or steel, would be very heavy and therefore difficult to handle. The use of carbon composites yielded a light and rigid table hatch which is used for patient treatment.

Adjustable neck support
An adjustable neck support for radiation treatments in the head and neck region has been constructed (see Fig. 1). For keeping the patient in a fixed position during treatment, a customised mask attached to an adjustable PMMA plate is often used. The attenuation of a 10 × 10 cm perpendicular incident X-ray beam by such a PMMA plate is about 3% for a 8 MV photon beam and 6% for

a 4 MV photon beam. Because the PMMA plate is sometimes only partly in the treatment field, and a PMMA cover strap is used to attach the customised mask to this plate, inhomogeneous dose distributions will result. The dose to the skin of a patient also increases due to the presence of the PMMA plate in the X-ray beam. The amount of the increase depends on the distance of this plate to the skin of the patient, the field size and the energy of the photon beam. In practice, an increase of up to 100% is not exceptional. Figure 1 shows the new neck support made from a hybrid plate consisting of two layers of carbon composite of 0.5 mm thickness and a 1 cm thick layer of PMMA foam. With the use of this hybrid plate the attenuation of an 8 MV X-ray beam is about 0.4%. The dose to the surface is less than 40% in the presence of the neck support.

Head support for CT scanner

A head support is made for a CT-scanner (see Fig. 1). Apart from the weight and rigidity of this construction, an additional advantage of carbon fibre composites compared with glass fibre composites, of which the head support was made initially, is that there are no disturbing effects of the support on the X-ray images.

Conclusions

After a time-consuming initial stage, in which a number of problems had to be solved such as the determination of specific types of releasing agents, the creation of a smooth surface and especially to master the processing techniques, we are capable of producing carbon fibre composites with comparatively few problems. The large number of potential clinical applications justify such an effort. For the construction of accessories which have to be used frequently for patient treatment, carbon fibre composites are replacing conventional materials more and more in our Institute. In many other cases carbon fibre composites are a very promising material for future replacements of more heavy construction materials.

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