Recent Developments in Oriented Polymers for Biomedical and Engineering Applications

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Summary: A review is presented of recent research at Leeds University which has been directed at devising novel methods for the production of oriented polymer structures. First, the new hot compaction process for oriented fibre and tapes is described, together with its applications to polyethylene and polypropylene where there are a number of practical developments. Secondly, there is the use of hydrostatic extrusion to make load bearing oriented products from hydroxyapatite filled polyethylenes. The production routes include the application of high pressure annealing prior to hydrostatic extrusion and the preparation of high modulus polyethylene fibre/hydroxyapatite billets as the starting point. Finally, recent progress on die-drawing as a means to producing oriented monofilaments and biaxially oriented tubes is described, where the applications include polymer ropes, pipes for gas and water distribution and transparent cans for packaging.

Keywords: compaction, hydrostatic extrusion, die drawing

Compaction of Fibres

In the hot compaction process a tightly packed array of fibres is heated under pressure to a temperature just below the peak melting point sufficient to melt a thin skin on the fibre surface [1]. On cooling, this thin skin of polymer recrystallines to form the matrix phase of a fibre reinforced composite, where both fibres and matrix are of identical chemical composition.

A wide range of fibres has been subjected to hot compaction to make compacted sheets whose mechanical properties have been determined and structural studies undertaken, most importantly by electron microscopy (in collaboration with Professor D.C. Bassett and his colleagues at Reading University). Ultrasonic measurements enable all the fibre elastic constants to be determined for comparison with theoretical values obtained by computational modelling. Hot compaction studies have been undertaken for polyethylene fibres (both melt spun and gel spun) polypropylene, polyester and thermotropic liquid crystalline fibres.

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For practical applications, it is most effective to make hot compacted sheets by compaction of woven fabrics and this can be achieved by several methods; a batch process using a hot press or an autoclave have been largely used to establish the technology; continuous processing was developed to provide a firm basis for commercial developments. The commercialisation of the hot compaction technology is now in the hands of BP Amoco and the material is being marketed under the trade name Curv™.

To date, the commercialisation of hot compaction has been concentrated on polyethylene and polypropylene. In the case of polyethylene, two major applications are radomes where the very low absorption of electromagnetic radiation is important, and protective helmets where high ballistic performance is required. For hot compacted polypropylene sheet there appear to be several major applications. The combination of lightweight, high impact performance, postformability and recycling suggest applications for automobiles. A more specialist application is for loudspeaker cones, where the compacted sheets show an excellent combination of stiffness and damping characteristics.

Hydrostatic Extrusion

Hydrostatic extrusion of polymers was first studied in the 1970s by groups from USA and Japan as well as at Leeds University. There have been two recent developments in the subject. First there is the hydrostatic extrusion of chain extended polyethylenes produced by annealing under pressure at high temperatures [2]. This has led to new understanding of the mechanisms of orientation and development of properties, and also of the role of a molecular network in the deformation process. Secondly, there is the hydrostatic extrusion of composite materials based on isotropic polyethylene (PE) and hydroxyapatite (HA) which has been pioneered by Professor W. Bonfield (Cambridge University) as a bone substitute material. Hydrostatic extrusion of HA/PE provides a method of making a product with dramatically increased stiffness and strength, in the range of cortical bone [3]. It has been shown that there are added advantages to be gained by pressure annealing [4] of the HA/PE, and that other routes to similar products can be obtained by use of the hot compaction technology [5].

Die-Drawing

For large scale engineering applications, die-drawing can provide a wide range of products in the form of rod, sheet and tube. Recent research on die-drawing has focussed on:-

(a) analyses of the mechanics of die drawing for rod and tube [6].

(b) development of integrated continuous processes [7] for profiles, polymer wires and biaxially oriented tubes.

The analyses of the mechanics of the die-drawing follow a similar route to that used for hydrostatic extrusion, i.e. a balance of forces within the die as in the Hoffman and Sachs analysis for extrusion of metals, together with geometric considerations to determine the strains in individual elements. The pressure dependence of the flow stress can be neglected for die drawing, a major difference from hydrostatic extrusion, where it is of importance.

A very wide range of die-drawing products has been produced, several of which are presently being commercialised. These include fluted cores for metal wire ropes, polymer wire ropes, biaxially oriented pipes in polyethylene and PVC and transparent PET cans for fruit packaging.

Conclusion

Several new routes to the production of oriented polymers for practical applications have been presented. These routes all involve the application of new science to a range of very well specified products . Hot compaction of fibres and tapes offers a very versatile method for making end products and two points should be emphasised. First, this method is very widely applicable, not only to polyolefines which have been the first to be exploited but also to polyesters, nylons and even liquid crystalline polymers. Secondly, in each case it is important to define the key properties required and these are not limited to improved stiffness and strength. Hydrostatic extrusion is of more limited application and even in the case of biomedical materials will take much longer to become accepted. Die drawing, on the other hand, is another versatile method, widely applicable to a range of products in many polymers. After a rather long period of development, it is gradually becoming adopted, especially as it is recognised that orientation may well offer a more commercially attractive alternative to improved properties than the use of more expensive polymers.

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