SOME STUDIES ON FIBRE LENGTH ATTRITION DURING PROCESSING AND THE INFLUENCE OF FIBRE LENGTH DISTRIBUTION ON MECHANICAL PROPERTIES OF SHORT GLASS FIBRE-REINFORCED POLYPROPYLENE COMPOSITES

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To My Parents

CERTIFICATE

This is to certify that the thesis entitled " SOME STUDIES ON FIBRE LENGTH ATTRITION DURING PROCESSING AND THE INFLUENCE OF FIBRE LENGTH DISTRIBUTION ON MECHANICAL PROPERTIES OF SHORT GLASS FIBRE-REINFORCED POLYPROPYLENE COMPOSITES" being submitted by Mr. P.K. Sharma to the Indian Institute of Technology, Delhi for the award of the degree of DOCTOR OF PHILOSOPHY is a record of the bonafide research work carried out by him. He has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis which, to our knowledge, has reached the requisite standard.

The thesis, or any part thereof, has not been submitted to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Glass fibre-reinforced thermoplastics represent a very rapidly growing area of the reinforced plastic industry today. They have a wide range of applications which are generally based on injection moulding or extrusion of extrusion - compounded short glass fibre-containing thermoplastic granules to yield useful products. Both the feed-stock requirements for this process and the high shear rates that the material encounters during processing, result in only short fibres being present in the finished article. Since composite properties depend significantly on fibre length, it is of obvious interest to study the attrition of fibres during processing and also to evaluate the effects of fibre length on mechanical properties. The composite properties are also known to strongly depend on the interfacial bond between the fibre and the matrix, a good bond being achieved by incorporation of a coupling agent in the composite. These two aspects, the first relating to fibre length and the second to fibre-matrix interface characterisation have been investigated in some detail for short glass fibre-reinforced polypropylene, which represents an important class of short glass fibre-reinforced thermoplastic systems. The results are presented and discussed in this thesis.

The interfacial shear stress was first evaluated using two different approaches in an extruded short glass fibre-reinforced polypropylene sheet having good fibre alignment along the extrusion direction. The first approach which is based on the model of Cox[8], considers the matrix to be elastic and results in the interfacial shear stress increasing linearly with composite strain. The second approach, which is based on a modified rule of mixtures[7,30,46] assumes that the interfacial shear stress is directly proportional to composite stress. On this scheme, upto 0.8 per cent composite strain, the interfacial shear stress was found to be identical to that predicted by the first model and it was also found to increase linearly with composite strain. At higher strains, however, it departed from linearity and the rate of increase was smaller. Since this latter approach gave quite consistent results, it was investigated in greater detail by making uniaxial stress - strain measurements with the sample cut from the sheet at different angles to the extrusion direction. The orientation effects were taken into account by two different procedures. In the first procedure the stress and strain along the loading axis of the specimen are considered and the computed orientation factor is found to be close to $\cos^4\theta$, for $\theta \lesssim 45°$ (θ is the angle between the extrusion direction and the fibre axis direction in the sample). In the second procedure, the fibre orientation in the sample is taken into account by taking the resolved components of stress and strain in the fibre axis direction. The transverse strain is also considered with the help of experimentally determined values of Poisson's ratio. The second procedure was found to be very satisfactory and it also confirms the assumption made in the second approach of linear dependence of interfacial shear stress on the tensile stress in the fibre direction.

The attrition of fibre resulting in the reduction of fibre length during extrusion and injection moulding was next-studied for two samples which were commercially available in the form of granules containing 30 per cent by weight of glass fibres. The first sample (short fibre granules) contained very small fibres of average length around 0.5 mm while in the second sample (long fibre granules), the length of the fibres was around 9 mm. In both cases fibre attrition was found to occur predominantly at the solid-melt interface in the melting zone of the extruder. However, in the sample containing small fibres the maximum of the length distribution, which for the initial sample is around 0.5 mm, moved to shorter fibre lengths along the screw channels farther from the hopper; finally reducing to an average length of about 0.4 mm. In the sample containing comparatively longer fibres (~ 9mm), a bimodal length distribution was obtained in the intermediate channels; the first maximum was around the original length of 9 mm and the second maximum centred around 0.5 mm. Thus the forces at the solid-melt interface result in fibre breakage to lengths which are predominantly around 0.5 mm. The fibre attrition was observed to be more severe in injection moulding apparently because of higher shear rates and also because the fibres had to pass through narrow channels. These results indicate that if the starting fibres in the granules are long, the average fibre length can be higher in the extrudate, perhaps due to the presence of undispersed fibre bundles that remain mostly undamaged. Uniform dispersion of fibres requires further processing which results in further breakage of fibres.

The possible mechanisms of fibre breakage were next considered. The bending moment exerted by the moving melt during extrusion was calculated and this was shown to cause the breakage of fibres to lengths of 0.5 mm or thereabouts. The possibility of breakage by post-buckling deformation was also considered as an additional mechanism of fibre breakage.

The load-elongation characteristics of injection moulded dumbbells from both the samples viz. based on short and long fibre granules were determined at -43°, 20°, 55° and 90° C. The results were analysed in terms of the effects of fibre length distribution and of the adhesion between the fibre and the matrix. The samples prepared from short fibre granules,which contain a coupling agent, inspite of short fibre lengths, give higher strengths, particularly at the higher temperatures, apparently because of good adhesion between the fibre and the matrix. The strength data on these samples was then analysed in terms of decrease in interfacial shear strength with increasing temperature. The impact properties of these samples were studied at room temperature and it was found that higher the average fibre length, higher is the impact strength. Fibre agglomeration was found to adversely affect stiffness and strength but not toughness.

Acoustic emission from these samples during the uniaxial deformation was also monitored and it was found that debonding of the interface and pull out of the glass fibres are the main mechanisms of energy dissipation and contribute predominantly to the toughness of the composite. This finding received further support from scanning electron microscopic studies of fracture surfaces of dumbbells.

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