INFLUENCE OF SOME PROCESSING PARAMETERS ON MECHANICAL AND TRIBOLOGICAL PROPERTIES OF INJECTION MOULDED GLASS FIBRE REINFORCED POLYPROPYLENE COMPOSITES

By

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Dedicated to

The noble cause of education

CERTIFICATE

This is to certify that the thesis entitled, **Influence of some processing parameters on mechanical and tribological properties of injection moulded glass fibre reinforced polypropylene composites,** being submitted by **Mr. H. Suresh Hebbar** 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

Many fibre reinforced polymer materials offer a combination of strength and modulus that are either comparable or better than traditional metallic materials and their alloys. The emphasis nowadays is therefore to replace metals and alloys by polymer composites in many weight critical components in aerospace, automotive and other industries. Such 'advanced composites' comprise of continuous fibres reinforced in thermoset type of polymers and offer the best advantage. But the processing techniques of these composites limit them for low volume of production. So for high volume production, fibre reinforced thermoplastic polymer composites are used. Moreover, thermoplastic resins offer some advantages over thermosets such as unlimited shelf life, reformability, higher impact resistance and potential for improved structural integrity.

Some of the applications may involve moving machine assemblies where due consideration must be given to mechanical and tribological properties of materials. Polymers offer excellent friction and wear characteristics in absence of external lubrication and provide maintenance-free operation, excellent corrosion resistance and good damping properties. Reinforcement of polymers by fibres enhance the tribological performance. As the reinforcing compositions are arrived at empirically for such applications, there is a need for understanding the influence for reinforcing fibres so as to optimise their compositions.

Among the many thermoplastics, polypropylene (PP) has been found to possess unique combination of properties and cost. So PP is emerging as a commercially interesting thermoplastic. To improve its properties reinforcements of higher aspect ratio must be used and E-glass fibres are the most appropriate because their cost is in the same range as that of (PP) Research work has been reported on fibre reinforced PP being developed

as a material for load bearing automobile components such as leaf spring and connecting rod. So the current focus seems to be on exploring mechanical properties like strength and stiffness as well as tribological properties like friction and wear.

Among various processing techniques the injection moulding is a versatile and economical method. So the use of the reinforced PP processed by injection moulding has been consistently higher in recent years. Because of considerable fibre attrition during injection moulding, this process produces short fibre composites. The flow-aligned fibre orientation gives a typical skin-core-skin structure to a moulded component. The fibres in the skin layer are aligned in the direction of the mould flow whereas the core fibres are aligned transverse to the mould flow. There exist correlations between most of the processing variables like screw speed, back pressure, barrel temperature, melt temperature, mould temperature and injection speed on the fibre -length distribution and in turn, on the fibre orientation distributions in the moulded components. These fibre related profiles finally determine the proportions of the skin and core in the moulded component and impart the mechanical and tribological properties.

Another aspect of the mechanical behaviour of engineering materials is the influence of temperature on properties like stiffness, strength, wear resistance etc. At temperatures significantly above room temperature, mechanical properties of thermoplastics, especially strength and stiffness are normally reduced. Reinforcement of the plastics with fibrous materials decreases the magnitude of this effect. Knowledge of these properties at higher temperature will help in diversifying the applications of these composites involving higher operating temperatures. Short fibre reinforced plastics have shown considerable improvement in the tribological properties of plastics. However, the orientation of the fibres with respect to sliding direction has a considerable influence on the tribological properties of these composite systems. There is only a limited effort in investigating these effects for PP and its composites.

In view of the above, there was clearly a need for systematic studies on injection moulded glass fibre reinforced PP composites to explore their mechanical and tribological properties and to find if there is any correlation between processing parameters, mechanical properties and the tribological properties at normal as well as higher test temperatures. Such a correlation will help one to produce composites having optimum mechanical and tribological properties, for different applications.

The present work is an attempt to fulfil this objective wherein two processing parameters have been considered. Accordingly, two sets of composite specimens were used. One set had the composites processed at four different back pressures, keeping other processing parameters constant. The second set had composites processed at four different barrel temperatures, while maintaining constant back pressure. All these specimens were in the form of a standard tensile coupon.

By burnout tests, it was found out that the volume fraction of fibres in these composites was 20%. The fibre length and orientation distribution were measured using image analysers. It was seen that the volume average fibre lengths in the composites of first set decreased with increase in the back pressure. The orientation distribution measurements indicated a typical skin-core-skin structure in these composites. The skin fibres were aligned in the injection direction and the core fibres in the transverse direction. The thickness of the core decreased with increase in back pressure.

The mechanical properties such as tensile strength, tensile modulus, tensile failure strain, flexural strength and flexural modulus of these composites were determined using an electro mechanical type of materials testing machine. These tests were conducted at four test temperatures of 27, 50, 75 and 100°C. The impact strength of some of these composites was determined using CEAST tabletop type Izode impact tester at room temperature. These tests indicated that the tensile strength decreased with increase in back pressure while the trend for the variation in tensile modulus is not so obvious. The tensile failure strain increased with increase in back pressure. The flexural properties showed larger scatter compared to tensile properties and no clear trend with respect to back pressure was observed. Increase in test temperature decreased the tensile strength, tensile modulus, flexural strength and flexural modulus. The variation of tensile failure strain with test temperature depended on the back pressure. The impact test results indicated that the impact strength of PP gets enhanced by a factor of thirteen with reinforcement of 20% volume fraction of long glass fibres. The variation in barrel temperature, as another processing parameter, did not show appreciable influence on the extent of fibre attrition during the processing of PP composites by injection moulding. Accordingly, the mechanical properties of the composites did not vary with change in the barrel temperature during processing.

The tensile failure modes of the PP composites were determined through the scanning electron microscopic investigations. It was found that the failure of the composite in the skin region was predominantly by fibre breakage at test temperature of 27°C and mostly by fibre pullout at higher test temperatures. The failure in the core region of these composites was predominantly by interface or matrix failure.

The friction and wear properties of these composites were found under the abrasive and sliding wear modes for the parallel, antiparallel and normal orientations of fibres with respect to the sliding direction. The abrasive wear test were conducted using scratch adhesion tester and pin on disc machine when abrading against SiC abrasive paper of mesh size #400. In scratch adhesion tester the composite sample abraded the fresh portion of the abrasive paper during each stroke whereas in pin on disc machine the sample was made to abrade on the same circular track throughout the test. These tests indicated that when the abrading specimen had contact with fresh portion of the abrasive surface for every stroke, the specific wear rate of PP was enhanced by glass fibre reinforcement. At lower test load(20N), normal orientation of fibres recorded maximum specific wear rate and at higher test load(60N), antiparallel orientation showed maximum specific wear rate. Parallel orientation had minimum specific wear rate at both the loads. When the relative motion between the two contacting surfaces was of rotation type and the specimen had a continuous contact with the abrasive paper, glass fibre reinforcement decreased the specific wear rate of PP. Parallel orientation showed minimum specific wear rate whereas normal orientation showed the maximum.

The sliding wear tests were conducted against a steel disc counterface under unidirectional and reciprocating sliding conditions. Unidirectional sliding tests conducted using pin-on-disc machine indicated that the glass fibre reinforcement decreased the specific wear rate of PP. With increase in back pressure the specific wear rate in parallel orientation increased whereas in antiparallel orientation it decreased. The specific wear rate of counterface disc was more with composites of PP compared to that of unreinforced PP. The sliding wear tests under reciprocating sliding conditions were conducted using SRV Optimol test machine at three test temperatures of 27, 50 and 75°C. These tests did not indicate a clear trend in variation of specific wear rate with back pressure. The counterface disc wear was negative(material deposition) in some of the tests. The specific wear rate of unreinforced PP increased with increase in test temperature whereas the specific wear rate of PP composites decreased with increase in test temperature. Coefficient of friction of PP composites was more than that of unreinforced PP under the abrasive wear mode and decreased with increase of test load. Under sliding wear modes, the coefficient of friction of PP composites was less than the coefficient of friction under abrasive wear mode. The difference in the coefficient of friction for unreinforced PP and composites of PP was marginal under sliding wear mode. The effect of the change in barrel temperature on the tribological properties is marginal and not very conclusive.

The theoretical model based on simple strength of materials considerations and on the three layer structure developed to correlate the tensile and flexural behaviours of injection moulded fibre-reinforced PP composites (with a typical three-layer structure) has been found useful in explaining the experimental results obtained in the present research work. Reasonable correlations between the mechanical and tribological properties of were obtained when the wear volume of PP composites recorded under abrasive wear mode were plotted against (tensile failure strain)$^{-1}$ and (tensile strength x tensile failure strain)$^{-1}$.

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