POLYETHYLENE: THE NEXT FRONTIER FOR SELF REINFORCED POLYMER COMPOSITES

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Introduction

Self reinforced polymer composites, or self reinforced plastics (SRPs), are a family of materials which, while having been around for several decades, have only recently been subject to a large amount of commercial interest. SRPs are a family of fibre reinforced thermoplastic composites where in the fibre reinforcement is made of the same (or a very similar) grade of polymer as the matrix material. While this presents problems in processing, due to the narrow processing temperature window, it also bears many rewards in terms of weight, mechanical properties and recyclability.
Currently commercially available SRPs are all manufactured from polypropylene (PP) and polyethylene terephthalate (PET). The research presented in this paper details development of an SRP manufactured using polyethylene. The use of polyethylene (PE) can provide higher stiffness and impact properties and allows lower processing temperatures than polypropylene (PP) and thus reduces energy consumption. Different types of PE were investigated to ascertain which grades would combine to give the best SRP. The mechanical properties of the resulting laminate were then studied.

Experimental

Materials
Polyethylene (PE) is the simplest of the thermoplastic polymers. Although having a very simple repeating unit, polyethylene does have several variations derived from the amount of branching present within the polymer's structure. Each of these variations gives rise to different mechanical and thermal properties.
Figure 1 shows the different structures of 4 different types of PE; low density polyethylene (LDPE) which has large amounts of long branches, linear low density polyethylene (LLDPE) which has quite a high amount of relatively short branches, high density polyethylene (HDPE) and ultra high molecular weight polyethylene (UHMWPE) which both have very low levels of branching.

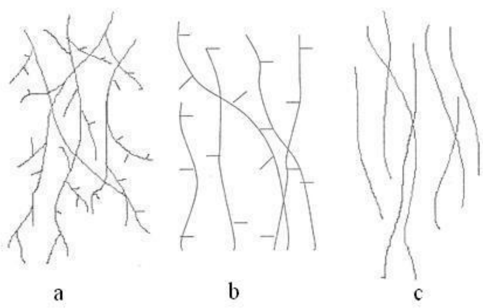

Figure 1: Structure of a) LDPE, b) LLDPE, c) HDPE/UHMWPE

Based on the properties of the 4 different types of polyethylene given in table 1, ultra high molecular weight polyethylene was chosen as the reinforcement polymer and high density polyethylene was chosen as the matrix material. The UHMWPE yarns chosen as the reinforcement had a tensile modulus of 97GPa. The UHMWPE yarns were commingled with a standard HDPE in a ratio of 50:50 by weight. The resulting commingled yarn was woven into a 2x2 twill weave fabric with a weight of 560gsm.

	Tensile Modulus (GPa)	Melting Point (°C)
LDPE	0.15-0.24 [1]	110[2]
LLDPE	0.25-0.5 [3]	119-129[2]
HDPE	0.55-1[1]	>129[2]
UHMWPE (Fibre)	Up to 113[4]	150[5]

Table 1: Properties of different varieties of PE

The fabric was consolidated into rigid sheets by the application of heat and pressure using both compression moulding (CM) and vacuum consolidation (VC). A range of pressures and temperatures were used during the consolidation process and are displayed in table 2. The resulting laminates were subject to tensile and flexural testing.

Sample No.	Forming Method	Pressure (bar)	Temperature (°C)
1	VC	0.91	135
2	VC	0.91	140
3	VC	0.91	145
4	CM	20	132
5	CM	20	141
6	CM	20	146
7	CM	20	151
8	CM	20	154
9	CM	10	145
10	CM	15	146
11	CM	25	145
12	CM	30	146

Table 2: List of forming parameters for SRPE laminates

Apparatus and Procedures

Tensile and flexural testing was carried out on an Instron 3367 30kN load frame equipped with a 30kN load cell. Data logging and analysis was carried out using Instron's propriety software and moduli were calculated between 0.05-0.25% strain. Tensile tests were carried out in accordance with ISO 527-4 and flexural tests in accordance with ISO 14125.

Results and Discussion

Figures 2 and 3 clearly show similar trends in the tensile and flexural properties of the laminates. For mouldings completed at a given pressure an increase in temperature yields higher strength and stiffness, however sample 8 shows that a temperature of 154°C is too high as both the tensile and flexural moduli drop off compared to sample 7. This is because at this elevated temperature the UHMWPE fibres soften, allowing the aligned polymer chains within them to relax into an unaligned state and thus lowering the mechanical properties of the fibres themselves, which in turn results in a weaker composite.

The trends also show that laminates consolidated at a given temperature (~145°C) show an increase in strength and stiffness as the forming pressure is increased. Both flexural and tensile properties show a maximum at 30bar forming pressure. This is due to greater compaction of the laminates and as such a lower void content of the resultant composite material. For the same reason the compression moulded laminates are able to attain much better mechanical properties than the vacuum consolidated ones, e.g. a tensile modulus more than double that of the best vacuum consolidated laminate.

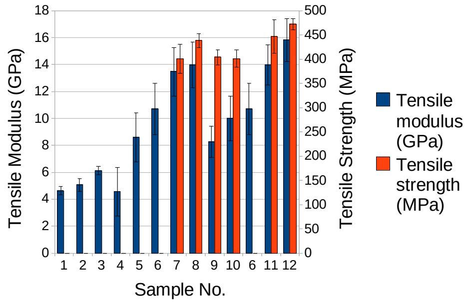

Figure 2: Tensile properties of laminates

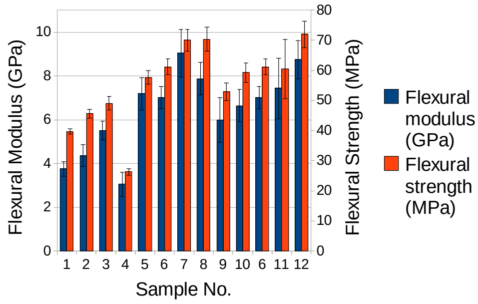

Figure 3: Flexural properties of laminates

Conclusion

Self reinforced polyethylene (SRPE) composites consisting of a HDPE matrix and UHMWPE reinforcement fibres have been successfully manufactured using both vacuum bagging and compression moulding manufacturing methods. Laminates achieved a flexural modulus and strength of 8.7GPa and 72.0MPa respectively and a tensile modulus and strength of 15.8GPa and 472.0MPa. SRPE shows great potential in applications where low weight is of the utmost importance due to its very low density and thus high specific mechanical properties.

References

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