Composites Science and Technology 103 (2014) 49–55

Contents lists available at ScienceDirect

Composites Science and Technology

journal homepage: www.elsevier.com/locate/compscitech

Effects of different fibers on the properties of short-fiber-reinforced polypropylene composites

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ARTICLE INFO

Article history:
Received 15 January 2014
Received in revised form 9 July 2014
Accepted 12 August 2014
Available online 19 August 2014

Keywords:
A. Fibers
A. Short-fiber composites
B. Mechanical properties
B. Fiber/matrix bond
Contact angle measurements

ABSTRACT

The aim of this paper is to give a comprehensive overview of the effects of different fiber types on the properties (flexural/tensile strength and modulus, notched and unnotched impact resistance, heat deflection temperature, density) of injection molded short fiber-reinforced polypropylene composites. The fiber length in the composite materials was analyzed, too. The influence of a coupling agent on the fiber/matrix interaction respectively the composite performance was investigated. Different sizings are compared for most fiber types. All fibers were characterized by contact angle measurements and their respective surface energies were calculated.

Most fiber types used show a reinforcing effect in accordance to the respective fiber properties. Comparison of different sizings and the use of a coupling agent show that fiber/matrix interaction has a significant impact on composite properties. A slight increase of the final fiber length can be achieved by using initially longer fibers. However, the results of this study indicate that a certain amount of adhesion is required for improving composite performance by increased fiber length.

1. Introduction

Short-fiber-reinforced polymers become more and more popular in various application fields like automotive or building and construction industry. They combine the advantages of polymers like good impact resistance and low weight with the high stiffness and strength of reinforcing fibers. In addition, most short fiber reinforced polymers are suitable for mass production as conventional techniques like extrusion and injection molding can be employed. The traditional reinforcing fibers are GF (see Table 1 for abbreviations), because they offer good strength and stiffness, impact resistance, chemical resistance and thermal stability at a low price. However, for a specific application other fiber types can be more suitable as they surpass the respective properties of GF. CF for example are used, when highest stiffness is required, while AF, PAN-F and PET-F show much better impact resistance compared to GF. Most fiber types, except for BF, have lower densities than GF making them more suitable for lightweight design [1–4]. Countless studies on fiber reinforced PP and even some studies comparing a small number of different fiber types are reported [1,5–9], but no comprehensive study comparing all the commonly used types of fibers exists. Results from different studies are hardly comparable, due to the variety of processing and testing techniques and parameters. Furthermore, most studies do not address the differences in fiber surface properties. But, beside the fiber type, the fiber/matrix interaction is the most influential parameter on composite performance. Adhesion supports the stress transfer from the matrix to the reinforcing fibers and hinders fiber pull-out, therefore improving the mechanical performance of the composite. Detailed descriptions for improvement of the fiber/matrix interaction, both fiber-based and matrix-based strategies, can be found in the literature [4,10–15]. Most commercially available fibers contain a sizing, thus possessing functional groups on the fiber surface. These functional groups are supposed to interact or even chemically react with the matrix polymer. As polyolefins have no functional groups that can interact with the fiber surface or the sizing, a coupling agent is usually added during compounding. For PP composites the most commonly used type of coupling agent is MAPP [4,15].

In addition to fiber type and fiber/matrix interaction, the fiber length has a major impact on composite performance [6,16–18]. Shearing stress during processing causes fiber fracture leading to wide fiber length distributions in composite materials. The length of brittle fibers like BF, CF and GF is usually reduced to a few tenths millimeters, almost regardless of their initial length [5,6,10]. More

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http://dx.doi.org/10.1016/j.compscitech.2014.08.014
0266-3538/

Table 1
Abbreviations.

Abbreviation	Explanation
AF	Aramid fibers
BF	Basalt fibers
CF	Carbon fibers
EP	Epoxy resin
Fm	Flexural modulus
Fs	Flexural strength
GF	Glass fibers
GPC	Gel permeation chromatography
HDT	Heat deflection temperature
IS	Impact strength
L_L	Weighted average fiber length
MAPP	Maleic anhydride-grafted polypropylene
M_w	Mass average molar mass
NF	Novoloid fibers
NIS	Notched impact strength
PA	Polyamide
PAN-F	Polyacrylonitrile fibers
PET	Poly(ethylene terephthalate)
PET-F	Poly(ethylene terephthalate) fibers
PP	Polypropylene
PU	Polyurethane
SFRPP	Short-fiber-reinforced polypropylene
Tm	Tensile modulus
Ts	Tensile strength
VE	Vinyl ester
v_F	Fiber volume fraction

elastic fibers like PAN-F or PET-F show less breakage, resulting in longer fibers in the composite [2]. These differences must be considered, when different fiber types are compared.

So, the aim of this paper is, to give a comprehensive overview of the effects of various fibers, differing in fiber material, fiber surface properties and fiber length, on the properties of SFRPP. To illustrate the effects of fiber/matrix interaction, fibers with different sizings were used and their surfaces were characterized by contact angle measurements using a capillary rise method. Due to the larger sample size, this method is less prone to inhomogeneities than other surface analysis methods such as XPS. However, no chemical functionalities can be determined using this method, but the calculated surface energies are an indicator for the amount of functional groups present at the fiber surface. For all fiber types composites were produced both without and with MAPP as coupling agent. Subsequently, for various fiber types, in particular AF, BF, CF, GF, PAN-F, PET-F and NF, an optimum sizing was selected and all fiber types were processed and tested under identical conditions. To illustrate the effect of fiber length on composite performance, different initial cut lengths were compared for one fiber type.

2. Experimental

2.1. Materials

All materials used for composite production are listed in Table 2. For contact angle measurements *n*-hexane, toluene, ethanol, ethylene glycol and water were used.

2.2. Compounding and specimen preparation

For comparison of different sizings and cut lengths for a certain fiber type, the fiber content was kept constant at 30 wt.%, an amount commonly used in scientific studies and commercially available compounds [2,4,10,12,16], while the amount of MAPP, when used, was 2 wt.%. For comparison of different fiber types, another series of experiments with a constant fiber volume content of 15 vol.% and an MAPP content of 3 vol.% was conducted, as composite performance is determined by the fiber volume fraction [6]. When different sizings were available for a certain fiber type, the fiber leading to the best overall package of mechanical properties was used.

Compounding was performed in a BRABENDER 350E mixer using Roller blades. The mixer was operated at 180 °C and 75 rpm. For experiments with constant fiber weight content, 200 g composite material were produced in one batch. For experiments with constant fiber volume content, 220 cm^3 composite material were processed at once. PP (and MAPP if used) was added first and mixed until melted for 2 min. Then the fibers were added and mixed for additional 5 min. Unfilled polymers were processed for 7 min under the same conditions. All compounds were ground in a FRITSCH Universal Cutting Mill PULVERISETTE 19 using a 6 mm square perforation sieve. From the milled compounds, tensile test specimens in accordance with EN ISO 3167 were produced using a BATTENFELD HM 1300/350 injection molding machine. The injection and mold temperatures were 190 and 60 °C, respectively. An injection speed of 50 cm^3/s was used for all specimens. The total cooling time was 30 s with a hold pressure of 80% of the resulting injection pressure being applied for the first 16 s.

Test specimens for flexural, impact and HDT-A testing were produced by cutting off the shoulders from tensile test specimens using a MUTRONIC Diadisc 4200 precision cut-off saw. This saw was further used to create a 2 mm notch in specimens for notched impact testing. For density measurements 20 mm × 20 mm plates were cut from the shoulders of tensile test specimens. All test specimens were conditioned at 23 °C and 50% relative humidity for at least 4 days before testing.

Table 2
Materials used for composite production.

Material	Manufacturer	Designation	Sizing*	Length (mm)	Diameter (μm)	Strength (MPa)	Modulus (GPa)	Density (g/cm^3)
PP	Borealis	HD120MO	–	–	–	33.5	1.5	0.91
MAPP	BYK Kometra	Scona TPPP 8112 FA	–	–	–	*x***	*x***	0.92
AF	Teijin	Twaron 1080	None	6	12	2866	67	1.44
AF	Teijin	Twaron 1488	PET	6	12	2866	67	1.44
AF	Teijin	Twaron 1688	PU	6	12	2866	67	1.44
BF	Asamer	Asa.Tec	EP	21	16.5	2850	82	2.60
BF	Asamer	Asa.Tec	EP	6	16.5	2850	82	2.60
BF	Asamer	Asa.Tec	VE	6	16.5	2850	82	2.60
CF	Toho Tenax	HT C604	PA	6	7	4000	238	1.76
CF	Toho Tenax	HT C493	PU	6	7	4000	238	1.82
GF	PPG	Chop Vantage HP3540	PA	4.5	10	2600	74.5	2.60
GF	PPG	Chop Vantage HP3299	PP	4.5	14	2600	74.5	2.60
NF	Kynol	KF 0301	None	1	18	170	4.45	1.27
PAN-F	Dolan	Dolanit 10D	None	6	18	880	17.7	1.18
PET-F	Performance fibers	713–699	None	4.4	22	880	9.6	1.38

* Polymer matrix recommended for the respective fiber type.
** No mechanical data is supplied by the manufacturer.