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ScienceDirect

Procedia CIRP 66 (2017) 277 – 282

www.elsevier.com/locate/procedia

1st Cirp Conference on Composite Materials Parts Manufacturing, cirp-ccmpm2017

Carbon fibre recycling from milling dust for the application in short fibre reinforced thermoplastics

Eckart Uhlmann, Paul Meier*

Institute for Machine Tools and Factory Management, Technische Universität Berlin, Pascalstr. 8-9, 10587 Berlin, Germany

* Corresponding author. Tel.: +49 (0) 30 314-23473; fax: +49 (0) 30 314-25895. *E-mail address:* meier@iwf.tu-berlin.de

Abstract

A new approach to reuse accruing chips and dust from milling operations of carbon reinforced plastics (CFRP) is studied, showing how CFRP milling dust, in comparison to primary and pyrolysed fibres, can find application as a filler material in thermoplastic granulates. Recent examinations show an overall better handling of milling dust when separating it into different classes of fibre lengths reaching up to 600 µm, which typically occur while machining reinforced plastics. Furthermore, the carbon reinforced polypropylene granulates have improved material properties, e.g. increased rigidity and tensile strength in dependence of their respective filler content towards non-reinforced plastics.

Peer-review under responsibility of the scientific committee of the 1st Cirp Conference on Composite Materials Parts Manufacturing

Keywords: fibre reinforced plastic; recycling; lifecycle

1. Introduction

Due to the focus on reducing the fuel consumption without influencing the integrity of structural parts in the aeronautical and automotive sectors, lightweight strategies are being pursued continuously [1]. Thus, these industries are processing almost 50 % of the global market share of CFRP [2]. The advantages over common lightweight materials like aluminium and magnesium alloys include its low density and its high tensile strength [3]. The demand for CFRP is growing steadily, which causes a predicted global usage of approximately 116,000 t in the year 2022 [4]. However, until today there are no standardised processes available for recycling CFRP to ensure a further use of fibre and matrix after reaching the end of its material lifecycle.

Moreover, even with near-net shape manufacturing techniques like Resin Transfer Moulding, trimming, deburring or drilling is still necessary. These post-processing steps lead to accruing chips and dust. This production waste disposal, which is estimated to be over 30 %, ends up in landfilling and incineration processes [5, 6]. This is mainly due to the inherent characteristic of thermosets, commonly used as the matrix for CFRP, not being fusible. Yet, changes in legislation, especially in the EU, make material recycling necessary [7]. One alternative way is the use of pyrolysis to dispose of CFRP, however this process is non-economic without reutilizing the carbon fibres [8, 9]. In terms of sustainability and a closed material cycle, new and environmentally friendly approaches with regard to this issue have to be found. A promising possibility is the application of CFRP waste in the form of milling dust or chopped material as a filler or additive in thermoplastics. In this study an attempt is implemented for injection moulding on polypropylene (PP). Besides the aspect of regaining material, better mechanical properties can be achieved. This is tested for different variations of filler content and fibre length to produce preferred variants for specific use cases. In addition to validating the performance of milling dust filled PP, primary and secondary (pyrolysed) fibres are also examined.

On the basis of sizing analyses, optical examinations and mechanical stress tests, a new material combination is being described in this paper.

Peer-review under responsibility of the scientific committee of the 1st Cirp Conference on Composite Materials Parts Manufacturing
doi:10.1016/j.procir.2017.03.277

Nomenclature

Latin symbols

A	amplitude
CF	carbon fibre
CFRP	carbon fibre reinforced plastics
d_f	fibre diameter
E	Young's modulus
F_{max}	maximum force
I	interval
l_f	fibre length
l_E	clamping length
m	mass
M	mesh size
PP	polypropylene
q_m	mass flow
RTM	resin transfer moulding
SFRP	short fibre reinforced plastics
Shore D	hardness
t	time
t_T	testing time
T_p	pyrolysis temperature
v_T	testing speed
w_m	mass fraction
w_f	filler content
w_{fb}	fibre content

Greek symbols

ε	strain
ε_B	elongation at break
σ	stress
σ_{max}	ultimate tensile strength

2. Fibre sourcing and characterisation

2.1. Raw material overview

To investigate new applications of CFRP waste as a filler material in reinforced thermoplastics, three different carbon fibres were compared. They are defined as follows:

- Milling dust
- Primary fibres
- Secondary (pyrolysed) fibres

The sourcing itself was realised in cooperation with CarboNXT GmbH, Wischhafen, Germany. The initial shape of the raw material was provided in milled form, thus leading to better processing in the subsequent injection moulding trials. The milling dust represents industrial waste from machining semi-finished CFRP products. The dust itself predominantly consists of fibre bundles embedded in epoxy resin due to their adhesive forces. Depending on the used process parameters, the typical fibre lengths range from l_f = 10 µm to l_f = 1000 µm. The primary and secondary fibres on the other hand are not compounds, but comprise only of carbon fibres with an average length of approximately $l_f \approx$ 500 µm according to company information. Primary fibres are typically used for textile processing and afterwards for the production of CFRP. These fibres are coated with a bonding agent for better interface connectivity, whereas secondary fibres can be seen as a recycled variant of primary fibres.

These secondary fibres underwent a pyrolysis. In this thermo-chemical process, the organic compound of CFRP is separated, disintegrating the epoxy resin and leaving a pure carbon fibre behind. The surface of secondary fibres as well as their mechanical properties are strongly dependent on the process temperature, which should range from T_p = 500 °C to T_p = 550 °C for epoxy resins [10]. By using this process, it is possible to recycle the fabric as a whole. An overview of the appearance of all fibre types is given in Fig. 1.

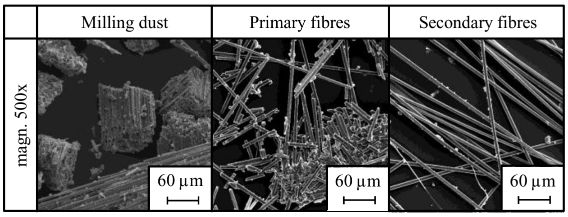

Fig. 1. SEM-images of the used fibre variants; (a) Milling dust; (b) Primary fibres; (c) Secondary fibres

2.2. Sizing and optical inspection

To differentiate the particle distribution of the carbon fibres within the supplied raw material, a classification of its length was conducted. Thus, a better prediction of the material properties was possible. First sieving tests with the different fibres were conducted with a test sieve shaker EML 200 from HAVER & BOECKER OHG, Oelde, Germany. The test sieve shaker has a closed system to reduce the dust exposure in the ambient air.

After first sieving trials with a mass of m = 100 g for each fibre variant, mesh sizes up to M = 710 µm were defined to display the fibre distribution, see Tab. 1.

Tab. 1. Applied mesh sizes in descending order

Pos.	1	2	3	4	5	6	7	8	9
Mesh size M in µm	710	600	150	125	106	75	45	32	20

The materials within mesh sizes M > 600 µm were mainly foreign matter or previous process-related parts related to carbon fibres. Only mesh sizes finer than M = 600 µm showed a homogenisation of the chip shape itself, making the dust more representative. Optical examinations as shown in Fig. 1 were conducted within the sieving trials for each fibre variant. Fig. 2 shows an exemplary overview of the sieved milling dust.