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A Hybrid Processing Approach to the Manufacturing of Polyamide Reinforced Parts with Carbon Fibers

M.Silva[a]*, A.M. Pereira[a], N. Alves[a], A. Mateus[a], C. Malça[a,b]

[a]*Centre for Rapid and Sustainable Product Development, Polytechnic Institute of Leiria, Rua de Portugal, 2430-028 Marinha Grande, Portugal*
[b]*Department of Mechanical Engineering, Polytechnic Institute of Coimbra, Rua Pedro Nunes, 3030-199 Coimbra, Portugal*

Abstract

The use of thermoplastic composites reinforced with long or continuous fibers underwent an amazing increase due to advantages such as good mechanical performance, high temperature resistance, recyclable and chemical stability when compared with simple thermosetting matrices. These advantages allowed for the replacement of thermosetting systems by composites that led to the discovery of new applications. However, the processing procedure of thermoplastics reinforced with prepregs yarns entails some technological and scientific challenges mainly due to its high viscosity that results in difficulty and complexity in impregnating the reinforcements. Concerning engineering components market requirements, the polyamide thermoplastic matrices reinforced with carbon fibers have a huge demand due to the versatility of the applications where they can be used. This work presents, therefore, the development of a low-cost device that combines the Fused Filament Fabrication (FFF) additive manufacturing technique together with the processing and consolidation of thermoplastic prepregs yarns for manufacturing parts made of polyamide reinforced with carbon fibers without need of post-processing operations. To evaluate the mechanical properties of the polyamide reinforced with carbon fibers, samples were manufactured and three point bending and tensile tests were done. From results it was demonstrated the very high structural strength to both bending and tensile loads of tested material.

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Keywords: Fused Filament Fabrication; Reinforced polyamide composites; Carbon fibers; Thermoplastic prepregs yarns

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: author@institute.xxx

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1. Introduction

The manufacture of high-performance components for engineering applications can be heavily improved by long fibers incorporation according to specific deposition pathways. The current manufacturing system of Fused Filament Fabrication (FFF) presents a considerable combination of advantages mainly the deposition of strengthening long fibers, making the additive manufacturing of parts made in composites with a thermoplastic matrix accessible with a reduced cost. [1] This manufacturing technology allows for strengthening the components only in the regions and in the most requested directions according to service application. This feature is achieved by the use of fibers yarn with a reduced diameter, which are deposited following the requested guidelines allowing the deposition of micro reinforcements and under more extensive reinforcement areas. The components manufactured with this technology benefit equally from the advantages resulting from the use of thermoplastic matrix, including higher impact resistance, durability, chemical stability and high service temperature [2], [3], [4], [5].

A system of yarn deposition of long fibers (carbon) on thermoplastic matrix (polyamide), intended for use with an additive manufacturing system by FFF, was recently designed and built by the authors. After the construction of the deposition system sample, printing tests were produced and mechanical tests performed in order to characterize the parts. Long carbon fibers yarn, with average length of 100 mm were used in this work. The length of reinforcement fibres influences the mechanical properties of the produced composites. However, for very long length of fibers yarn, with an average of 100 mm, the influence of length in the Young modulus value of composite can be neglected when compared with continuous fibers [6]. This behaviour can be explained by the high aspect ratio given by the length on the diameter of the carbon fibres. Nevertheless, it must be highlighted that the developed FFF system can process also continuous fibers yarn.

2. Materials and FFF Equipment

It is well known that thermoplastic matrix composites present many advantages when compared to the thermoset composites, such as the greater resistance to fracture and deformation; the lower cycle time of processing do not require extra time for the chemical reaction of polymerization to occur (cure > > less processing time), the unlimited shelf life time of prepregs (unlimited storage and in demanding conditions no need for negative temperatures cooling), the good chemical resistance (solvents), the potential for application in manufacturing process, fast, clean and automatic, as they can be recycled. However, the molten of thermoplastics has a high viscosity (500-5000 PA.s) when compared with those presented by thermosets (typically 100 Pa.s), making your processing most troublesome [7]. This drawback results in a great difficulty for the impregnation of the reinforcement fibers, porosity and unpredictable low mechanical performance. It is precisely at this point that the aspects related to processing acquire strong relief. The development of new strategies of deposition and consolidation are the key to overcoming these constraints. One of the major challenges is the knowledge of the processing, which in recent years has gone from practices based on empirical procedures with known scientific basis and engineering principles. These processing difficulties require new processing techniques involving prepregs tapes and hybrid fibre reinforcement yarns. The knowledge concerning the processing/production assumes paramount importance in the current context of globalization and high competitiveness between companies, where the efficiency and speed of production are determining factors for success.

The thermoplastic matrices composites have *unic* characteristics, e.g. good chemical resistance, resistance to fracture and deformation and their superior mechanical performance when compared to composites made based on thermoset matrices, which are very promising for the composite industries. Furthermore, the post processing and the possibility of reprocessing (new shape), repair and recyclable, are some of the features that demonstrate the potential of cost savings that these materials can represent.

2.1. Carbon Thermoplastic Yarn (TPFL carbon fiber/PA12)

In the tests carried out along this work, related to additive manufacturing of thermoplastic composites, were done using the hybrid fiber yarn of carbon / PA12, under the trade name of TPFL produced by Schappe Techniques, France. TPFLs are dry prepregs that homogeneously combine reinforcement and matrix filaments. This yarn combines long carbon fibers (CF) and PA12.